NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

VISUALIZATION AND ASSESSMENT OF GLOBAL OCEAN DATA ASSIMILATION EXPERIMENT PROFILE DATA FOR THE PACIFIC OCEAN

by

Timothy A. Anderson

June 2001

Thesis Advisor: M. L. Batteen
Second Reader: D. Dimitriou

Approved for public release; distribution is unlimited.

REPORT DOCUMENTATION PAGE			*Form Approved OMB No. 0704-0188*
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instruction, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188) Washington DC 20503.			
1. AGENCY USE ONLY ***(Leave blank)***	**2. REPORT DATE** June 2001	**3. REPORT TYPE AND DATES COVERED** Master's Thesis	
4. TITLE AND SUBTITLE: Visualization and Assessment of Global Ocean Data Assimilation Experiment Profile Data for the Pacific Ocean			**5. FUNDING NUMBERS**
6. AUTHOR(S) Anderson, Timothy A.			
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Postgraduate School Monterey, CA 93943-5000			**8.PERFORMING ORGANIZATION REPORT NUMBER**
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) N/A			**10. SPONSORING / MONITORING AGENCY REPORT NUMBER**
11. SUPPLEMENTARY NOTES The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.			
12a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release; distribution is unlimited.			**12b. DISTRIBUTION CODE**

13. ABSTRACT *(maximum 200 words)*

The Global Ocean Data Assimilation Experiment (GODAE) is an endeavor that will likely change the path of oceanography for many years. This attempt to assimilate, organize and provide massive quantities of widely varied oceanographic and meteorological data to the world could be a catalyst for new and innovative research opportunities. One of the data sources important to GODAE and of great possible value, the Array for Real-time Geostrophic Oceanography (ARGO), is another innovation that may lead to significant improvements in oceanographic modeling and research. The concept of thousands of autonomous floats, reporting ocean conditions to a database that can assimilate and provide this data in real or near-real time, affords countless opportunities for new methods of ocean prediction.

The true test of GODAE is to assess the utility of the data available in a real world setting, and ascertain the relative usefulness as it relates to research opportunities and operational data needs. This thesis will assess the utility of the USGODAE data server by retrieving, processing, visualizing and employing the data to observe conditions in and near the Kuroshio Current. By attempting to use the data server in a method similar to future research and operational use, an understanding of its true potential may be reached.

14. SUBJECT TERMS Global Ocean Data Assimilation Experiment, GODAE, Array for Real-time Geostrophic Oceanography, ARGO, North Atlantic Ocean basin, drifting buoys, ocean state prediction, climate			**15. NUMBER OF PAGES** 92
			16. PRICE CODE
17. SECURITY CLASSIFICATION OF REPORT Unclassified	**18. SECURITY CLASSIFICATION OF THIS PAGE** Unclassified	**19. SECURITY CLASSIFICATION OF ABSTRACT** Unclassified	**20. LIMITATION OF ABSTRACT** UL

THIS PAGE INTENTIONALLY LEFT BLANK

Approved for public release; distribution is unlimited.

VISUALIZATION AND ASSESSMENT OF GLOBAL OCEAN DATA ASSIMILATION EXPERIMENT PROFILE DATA FOR THE PACIFIC OCEAN

Timothy A. Anderson
LT, USN
B.S., University of Notre Dame, 1995

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN PHYSICAL OCEANOGRAPHY

from the

NAVAL POSTGRADUATE SCHOOL
June 2001

Author: Timothy A. Anderson

Approved by: Mary L. Batteen, Thesis Advisor

David Dimitriou, Second Reader

Roland W. Garwood, Jr., Chairman
Department of Oceanography

THIS PAGE INTENTIONALLY LEFT BLANK

ABSTRACT

The Global Ocean Data Assimilation Experiment (GODAE) is an endeavor that will likely change the path of oceanography for many years. This attempt to assimilate, organize and provide massive quantities of widely varied oceanographic and meteorological data to the world could be a catalyst for new and innovative research opportunities. One of the data sources important to GODAE and of great possible value, the Array for Real-time Geostrophic Oceanography (ARGO), is another innovation that may lead to significant improvements in oceanographic modeling and research. The concept of thousands of autonomous floats, reporting ocean conditions to a database that can assimilate and provide this data in real or near-real time, affords countless opportunities for new methods of ocean prediction.

The true test of GODAE is to assess the utility of the data available in a real world setting, and ascertain the relative usefulness as it relates to research opportunities and operational data needs. This thesis will assess the utility of the USGODAE data server by retrieving, processing, visualizing and employing the data to observe conditions in and near the Kuroshio Current. By attempting to use the data server in a method similar to future research and operational use, an understanding of its true potential may be reached.

THIS PAGE INTENTIONALLY LEFT BLANK

TABLE OF CONTENTS

THIS PAGE INTENTIONALLY LEFT BLANK

LIST OF FIGURES

THIS PAGE INTENTIONALLY LEFT BLANK

LIST OF TABLES

THIS PAGE INTENTIONALLY LEFT BLANK

ACKNOWLEDGMENTS

This thesis would not have been possible withouot the efforts of several people. Professor Mary Batteen, who provided guidance and the initial idea that a degree was possible, made this goal a reality. CAPT Joe Swaykos, CAPT Jeff Bacon, and LCDR Dave Dimitriou, who supported a seemingly extraneous activity in an already busy schedule and gave me the leeway to pursue my goals. Antonio Martinho, who gave of his own time and helped some computer illiterate students do what needed to be done.

Most of all I want to thank Jennifer Hauser, who gave me the idea of pursuing a Master's Degree, showed me it was possible, and didn't let me quit when it got tough. Her determination and friendship are the core reasons for my success in this endeavor.

THIS PAGE INTENTIONALLY LEFT BLANK

I. INTRODUCTION

Meteorology and oceanography are two sciences that provide a natural conundrum for scientists. These areas of study involve a vast percentage of the earth's environment that is not naturally inhabited by humans, yet these same environments produce significant effects on every human's daily life. Understanding the oceans and atmosphere is imperative in determining not only their effect on the world's populations, but also the effect of the human population on the earth.

Past attempts to investigate the world's oceans and the atmosphere have yielded vast amounts of information, and provided significant breakthroughs by which society as a whole has benefited greatly. The direct relationship between understanding our environment and society's benefits are evident: use of weather prediction to enhance crop production, prediction of devastating storms to protect life and property, and short-term weather prediction to enhance the daily life of almost everyone in the entire world. These advances and benefits have been a direct result of the genius and innovation of many scientists, yet they have been limited by one basic factor: technology.

The ability to see into the depths of the oceans, up into the highest reaches of the atmosphere, and predict the future have just recently moved from the venue of science fiction novels to real scientific research. The past fifty years have provided an environment for fantastic growth in the investigation, research and understanding of the world's oceans. The many scientific developments have included satellite data collection, advances in acoustic profiling, *in-situ* measurement techniques such as the Conductivity-Temperature-Depth (CTD) measurement device, and numerical modeling advances.

These advances in ocean observation and prediction are remarkable in their own right. They, as well as many others, have provided a wealth of data and information to inspire new ideas and generate new concepts in oceanographic and meteorological research. The information generated from both observation and numerical modeling of the world's oceans is of great value to both the scientific community and to the entire world. The coupling of these advances, with recent exponential leaps in computers and data transfer networks, should provide even greater understanding of the air and ocean environment.

The Global Ocean Data Assimilation Experiment (GODAE) attempts to do this very auspicious task. Through very recent advances in computing power and data transfer techniques, the GODAE project will attempt to gather the worlds' oceanographic data in real or near-real time, organize it into a discernible form, and provide it to the world along with the output from several different numerical prediction models. This data source will hopefully be a wealth of information for future research and a boon to the oceanographic community and society as a whole.

This thesis will attempt to give a look into the GODAE project itself, and provide a view of the technology involved and the goals of the experiment. Another goal of this thesis is a practical example of implementation of the data available on the United States GODAE (USGODAE) data server, with emphasis on the usefulness of the data in oceanographic research. Using the results of this implementation, this thesis will attempt a basic assessment of the initial practicality of this system, and provide insight on the possible future uses of this project.

II. BACKGROUND

A. GODAE DEVELOPMENT

1. GODAE Goals

The inspiration for the GODAE project comes from a number of previous experiments that have attempted to provide similar understanding about the world's oceans. The preliminary successful experiments such as the Tropical Oceans - Global Atmosphere (TOGA) experiment and the World Ocean Circulation Experiment (WOCE), along with the rise of viable operational ocean activities, provided a significant amount of encouragement that an undertaking as auspicious as GODAE could be possible (Smith. 1998). The improvement of expendable bathythermographs (XBT) in the late 1960's provided a feasible method for observing temperatures in the upper ocean. These were widely used by research vessels, naval vessels, and also volunteer ships that would release XBT's into the water along whatever ship route they were transiting. This provided a sizable amount of data, but was mainly limited to the major shipping lanes and the small areas in which research vessels would venture during their work.

TOGA and WOCE were still further steps toward a comprehensive oceanographic picture. TOGA was an endeavor to produce consistent oceanographic data for the tropical Pacific Ocean, and to develop an understanding of the processes that were occurring there. A benefit from this endeavor was the discovery of the El Niño/ La Niña Southern Oscillation (ENSO) phenomenon, which proved to be instrumental in developing a prediction capability for future ENSO events. WOCE was conducted from 1990-1998 with the goal of producing the most complete hydrographic survey ever attempted. Approximately 9,000 top-to-bottom (CTD) profiles were collected in this relatively short

time, along with about 40,000 XBT observations (Smith, 1998). In comparison to previous experiments, WOCE collected a data set that had a very broad spatial coverage with a relatively compact temporal distribution. These experiments dealt mainly with ocean temperature, not salinity or velocity. Many of the observations, especially the XBT data, only went to 500-750m depths (AST, 1998). The data collected by these XBT observations was not nearly as accurate as results using more modern data collection instruments, and were concentrated in high traffic areas. Virtually no data was collected south of 30°S, leaving a vast portion of the world's oceans uninvestigated. This was one of many large areas where data collection was sparse or nonexistent.

Each of these projects is an experiment in the traditional sense: collection of data for a set time period, followed by analysis and review of the data pertaining to specific scientific questions, and presentation of the results to the public. WOCE will be a complete analysis of the data collected sometime soon. When the results are complete, they will be regarded as are most other experiments: a view of specific parameters applied to specific concepts from a specific time period of data. The TOGA project has successfully transformed into the Tropical Atmosphere Ocean array (TAO), but is still limited to the tropical Pacific Ocean, diminishing its use as a comprehensive source of data. These types of experiments are invaluable in the research arena for developing the science behind the understanding of the oceans. Although these experiments provided a wealth of knowledge that pushed oceanography forward as a whole, their impact will also be limited in ways. The data collected by these experiments, and subsequently the results, reflect the conditions of portions of the ocean for a specific period of time. The type of data collection for this experiment is soon to be surpassed by continuous

collection of data from the entire ocean, allowing for not only analysis of scientific concepts and theories in short time periods of data, but continual analysis and review of data to assess and improve our understanding of the oceans.

Other experiments, such as the Global Ocean Observing System (GOOS) and Global Climate Observing System (GCOS), had the basic concept of continual data assimilation in mind, but did not receive the level of commitment needed to successfully fulfill their goals (Smith, 1998). The Climate Variability and Predictability Program (CLIVAR), a project proposed by the World Climate Research Program (WCRP), has goals similar to GODAE, but as the name suggests, the focus of CLIVAR is long-term climate change and prediction. The idea of an all-encompassing data assimilation system, providing continuous access to vast and continuously updating databases, is daunting in its own right. Coupling this with the task of gathering data from every corner of the world's oceans only increases the complexity and allows for many avenues that could lead to failure. The belief that the results of experiments such as these would not be accessible for a significant amount of time resulted in a lack of support for these experiments. Projects that require years to collect, analyze, and produce results from oceanographic data are useful when assessing long-term changes in ocean conditions, not for short-term oceanographic prediction. A significant amount of real world interest lies in the real time analysis of data for use in short-term oceanographic analysis and prediction. When GOOS and GCOS were proposed, this stigma of not being able to successfully gather and analyze real or near-real time data from the ocean was a driving force in the lack of support, ultimately leading to the lack of success in these ventures (Smith, 1998).

Much has changed since these projects were first proposed over a decade ago. Advances in remote sensing capabilities have greatly improved our ability to cover vast amounts of ocean, gathering significant amounts of data in the process. Innovations in autonomous data recording equipment have also generated a new source of real time data. Gone are the buoys and drifters that would record observational data on material that was stored in the instrument itself, waiting for retrieval before its secrets could be examined. With the advent of satellite telecommunications and the Internet, data can be transmitted from a buoy or drifter in the most remote portions of the world's oceans, and be accessible by scientists within just a few hours, sometimes almost instantaneously. Other contributors to the expansion of observational gathering capabilities are the general advances in computing power, especially in data storage and transfer. Today millions of remote observations from satellites observations can be transmitted across the world and be stored, processed, and made available daily.

These advances coincide directly with the new need for timely, accurate, analysis of ocean conditions, as well as in-depth research into trends in climatology and predictions on what conditions can be expected in the near future and for years to come. Demand for oceanographic data comes from many areas. Coastal communities look to numerical modeling to predict deadly ocean conditions that may destroy their homes. The fishing industry is always interested in maximizing their efforts in finding areas in the oceans where they will have the best catches and be able to provide food to billions of people. Commercial shipping seeks the latest in ocean conditions and accurate forecasts to plan the safest and most efficient routes to move cargo around the world. The last, and possibly most important, is using oceanographic data to ensure the freedom of these

shipping lanes from danger, not by nature, but by our fellow man. These are areas where the growth in use of oceanographic data is occurring at an exponential rate, again due to both advances in the science behind oceanography, and the technology that delivers this information, from the observation platform to the analysis center to the end user.

GODAE's vision is:

> *A global system of observations, communications, modeling, and assimilation, that will deliver regular, comprehensive information on the state of the oceans, in a way that will promote and engender wide utility and availability of this resource for the maximum benefit to the community* (IGST, 2000).

The vision addresses this need for comprehensive real or near-real time data, and couples that with a source of data for varied research endeavors. The assimilation of all forms of oceanographic data collection into a unified, integrated system will allow researchers and scientists to not only access data for investigating new concepts and theories, but also provide a baseline of data to which future comparisons can be made, allowing for further understanding of what trends are occurring in our oceans worldwide.

The objectives of GODAE are:

- To apply state–of–the art ocean models and assimilation methods to produce short-range open-ocean forecasts, boundary conditions to extend predictability of coastal and regional subsystems, and initial conditions for models; and

- To provide global ocean analyses for developing improved understanding of the oceans, improved assessments of the predictability of ocean variability, and as a basis for improving the design and effectiveness of a global ocean observing system (IGST, 2000).

Specific goals include:

- Coordinate and foster a more efficient, responsive, and sustainable system for data assembly, quality control, and access;
- Improve public access to and awareness of the many marine services products, both operational and research that are available;
- Foster the development of a shared "Common" of ocean information and tools for the production of improved ocean products;
- Foster the production and analysis of improved ocean service products;
- Undertake experiments to assess the utility of various ocean data streams for different applications; and
- Guide the evolution of a global ocean observing system, until the system and tools are able to produce ocean service products that meet the needs of the GODAE sponsors.

GODAE's underlying concept is based on timely and consistent receipt of oceanographic observations from around the world, continuous numerical model output, efficient organization of data, and ease of access by the customer. GODAE intends that this resource be geared not only for the top-level scientists and researchers, but also for

all people who require this type of data in non-research endeavors. The anticipated outcomes of this project include:

- An improved capacity for prediction for the coastal, shelf, and regional subsystems through the provision of suitable oceanic initial and boundary conditions;
- Better initial conditions for climate predictions and analyses for validation of climate simulations;
- Improved open ocean nowcasts and forecasts;
- Integrated analyses or reanalyses for research programs (e.g. CLIVAR);
- Description of the ocean circulation and physics upon which more specialized systems, such as ecosystem models, can be developed and tested;
- A foundation for hypothesis testing, process studies, and further experimentation, much as is commonplace in numerical weather prediction today;
- Improved availability and utility of ocean data;
- A methodology for systematic handling, quality control, and consistent scientific interpretation (analysis) of special data sets such as those from process studies and arising from incidental exploration;
- Assessments of the observing system and of the utility of new ocean data sets (e.g. new altimetric missions, sea surface salinity from satellites);
- Model testing improvement;
- A viable long term observing system (GOOS); and

- Development of an enhanced user base and suit of applications (IGST, 2000).

GODAE differs from other experiments and projects in that the goal of GODAE is not proof of a scientific theory, analysis of certain conditions, or investigation of a specific area of the ocean, but a much broader view. The success of GODAE is based on much more abstract terms, as is discussed in the GODAE Strategic Plan. The plan refers to a "GODAE Common," where all GODAE partners are responsible for maintenance of oceanographic data and all are able to share the benefits of such a source of oceanographic knowledge (IGST, 2000). This "GODAE Common" is to include various elements:

- Assimilation products from existing national research and operational activities;
- GODAE-specific data products developed through existing facilities and new efforts;
- Infrastructure, such as data and product serves, assembled specifically for GODAE; and
- The knowledge base accumulated through joint development, intercomparison experiments, and other GODAE collaborations (IGST, 2000).

These requirements reflect the nature of GODAE as a solution to wider issues, the need for cooperation between the different groups in the oceanographic community, and integration of different elements of research to provide a greater whole solution to the question: "What goes on in our oceans?" To accomplish this lofty but still attainable

level, the Strategic Plan for GODAE includes principles and guidelines for the development of this project:

- GODAE has a sound scientific basis and a strategy that is based on scientific best-practice, but it is not a research experiment. It is a practical demonstration of feasibility and utility and of a near-real-time, routine global data assimilation;
- The GODE Common must be built on the paradigm of open, readily accessible, routine data and products;
- GODAE will build on existing scientific and operational capabilities where practicable, capitalizing on the developments and successes of WOCE and TOGA, and engender an effective partnership between the operational and research communities;
- GODAE will build on and advance national and international operational activities relating to ocean data assimilation;
- The global assimilation products for the operational phase of GODAE will be the synthesis of multivariate in situ and satellite data through global ocean models, for a diverse set of applications;
- GODAE will focus effort on the scientific and technical development of th e core information system;
- GODAE will develop value-added and specialist products through linkages and partnerships to other communities;

- GODAE will leverage off many operational and research efforts, from regional to global perspectives. The guiding principle for global and/or regional models and assimilation systems is that these activities should foster the development of the core systems of the GODAE Common;
- Ocean state estimation tools will provide a framework for quantifying the contributions from different data sources and new data types (such as remotely sensed salinity), thus improving the design an efficiency if the observing system;
- GODAE will progressively test and, as appropriate, adopt new technologies and scientific methods; and
- GODAE must lay the foundation for a long-term, sustained ocean observing system and a sustained routine ocean product line (IGST, 2000).

To accomplish this task, the International GODAE Steering Team (IGST), headed by Neville Smith from the Bureau of Meteorology in Melbourne, Australia, sought to develop a system that would allow for an integrated data storage and transfer capability, and also be scalable for future growth and development. The concept behind this is basic yet very robust: build a system that houses enough data storage for all estimated oceanographic data to be compiled into the GODAE data set, and implement a method of providing access to this data to all types of customers.

2. United States GODAE Server

The USGODAE data site at Fleet Numerical Meteorology and Oceanography Center (Fleet Numerical) in Monterey, California exemplifies the concepts of GODAE. Fleet Numerical is one of the preeminent high power computing centers in the world, and

deals specifically with both oceanography and meteorology numerical modeling. Fleet Numerical's primary mission is:

> *To combine innovative technology with the best available science in order to provide the best weather and oceanographic products, data and services to the operating and support forces of the DoD anywhere, anytime.*

To accomplish this mission Fleet Numerical must gather observational data, both meteorological and oceanographic, compile the observations into an accessible database, and use the data to implement various numerical models that analyze and predict the conditions of the atmosphere and oceans. This tasking matches directly with the needs of GODAE: a site to collect oceanographic data, knowledge in combining various types of data into a cohesive database, a source of meteorological data to supplement the oceanographic information, and knowledge in making vast amounts of data available to a varied customer base in a time-critical environment. These qualities make Fleet Numerical an excellent location for the USGODAE data storage and access site.

Fleet Numerical endeavored to implement an infrastructure that not only meets the current requirements for GODAE's initial implementation, but also is flexible enough to provide a platform from which growth and adaptation to new requirements and goals is possible. The concepts of a scalable system, with high availability and high reliability are the basis for the system's architecture. The design concept is very straightforward: multiple web servers to provide a connection point for customers to request data in various forms, a significantly large and robust data storage structure that will allow continuous and timely access to the data sets stored, an archive capable storage system

with significant memory, and a flexible yet fast network infrastructure to connect these parts of the system together and to the Internet. Fleet Numerical accomplished this design with Commercial Off The Shelf (COTS) and Government Off The Shelf (GOTS) hardware and software, allowed for scalable additions to the current system to increase the server capacity should customer load require, and has a plan for additional data storage and archive capability as successive years of oceanographic and meteorological data accumulates (Dimitriou, 1999).

An overview of the types of data to be stored and made available through the USGODAE site is shown in (Table 1). The data falls into four groups: atmospheric forcing (wind stress, wind speed, air temperature, specific humidity, precipitation) and sea ice, data for assimilation (altimetry, ocean profiles, sea surface temperature (SST)), validation data (hydrography), and ancillary data (climatology, bathymetry). The list is quite varied, and reflects the GODAE concept of gathering and providing all types and forms of oceanographic data, and related meteorological data for comparison. The meteorological data, such as wind forcing fields, temperatures, and heat flux, are significantly important in that they provide an account of the varied and significant effects of the atmosphere on the ocean. Another apparent quality of the data set is the varied sources of similar data types. GODAE did not attempt to nominate single sources for certain types of numerical model data. To the contrary, the varied sources shows that it is GODAE's goal to have a comprehensive and complete collection of data for comparison, research, analysis and assessment. These data types will be discussed further in the Data and Processing portion of this thesis.

B. ARRAY FOR REAL-TIME GEOSTROPHIC OCEANOGRAPHY (ARGO) DEVELOPMENT

1. ARGO Goals

GODAE's goal is to assimilate, organize, store, and make available a comprehensive oceanographic data set. GODAE identifies one basic need: access to comprehensive oceanographic data. Collecting data to study oceanographic processes has proved difficult for centuries for one basic reason: humans do not naturally live in the ocean. The concept may be simplistic, but the basic fact that very few humans venture out onto the ocean, and fewer still venture into the ocean deeper than a few meters, makes collecting observations of the ocean's conditions very difficult. In the last century man developed safe flying machines, and interest in the workings of the upper atmosphere exploded. Suddenly the need to investigate, analyze, conceptualize and predict the inner working of the atmosphere became vital to the aviation world, and to society as a whole. The development of meteorology from a conceptual science to a discipline that involved collection of *in-stiu* data, analysis, and most important, prediction, was not only a benefit to the people who risked life and limb in developing aircraft, but to a host of other groups, from Army Generals to farmers, Naval Captains to everyday people wanting to know in advance how the weather may affect their daily life. These developments were possible because of innovations in aviation that allowed people to fly high into the atmosphere at great speeds, and collect vast amounts of data in doing so.

The world's oceans have not been as hospitable to human exploration as the atmosphere. Where airplanes deal with pressure differences of up to ten pound per

square inch (PSI), ocean going submersibles have to withstand pressures of hundreds to thousands of PSI. The relatively slow speeds of travel, enormous pressure, and inherently dangerous nature of submarine exploration have severely limited the ability of humans to investigate the oceans and collect data. Up to the last decade, the largest source of data from the ocean came from ships traveling at very slow speeds, taking measurements by repeatedly immersing instruments into the murky depths and waiting for the results.

The advent of satellite technology has vastly improved the capability to collect more comprehensive data from the world's oceans. Both polar orbiting and geo-stationary satellites now provide a wealth of data from which SST, sea height, wind forcing, phytoplankton content, and a host of other parameters can be deduced. This remote form of observation is advantageous for the same reasons as remote observation of the atmosphere: the apparatus conducting observations can cover vast distances and record and transmit the data to receiving stations around the world. This ability to gather data for large areas of the world and have it available within minutes makes satellite observation a boon to the oceanographic community. No longer are researchers taking data from a very small area and extrapolating it to cover an entire basin. Data coverage of an entire bay, sea, basin, or the world is available to apply towards research and development.

An unfortunate drawback to this remote type of data collection is the same reason that it can easily take so many observations: the observation platform collecting the data is far away from the medium it is observing. This greatly limits the satellite's ability in two ways. The distance from the ocean precludes measurements of parameters such as

salinity, and the removal from the medium allows for extremely limited investigation below the ocean's surface. To really understand what processes are occurring in the world's oceans, a cursory look at the surface while passing by at upwards of 18,000 miles per hour is not sufficient. The answer to this need for *in-situ* data is an observation system that can record data from various depths in the ocean, and transmit that data to scientists and researchers for timely analysis.

ARGO is a system that compliments the concepts of GODAE. First touched upon in two different publications, (Roemmich, 2000, and Schmitt, 1998) the idea of an array of autonomous floats gathering observations around the world in real time and transmitting them to a central location for organization and assimilation into a data base, fell right into the arena of GODAE (AST, 1998). The primary practical goal of ARGO is:

> *Provide an enhanced real-time capability for measurement of temperature and salinity through the upper 2000m of the ocean and contribute to a global description of the seasonal cycle and interannual variability of the upper ocean thermohaline circulation* (AST, 1998).

The scientific goals of ARGO address unfulfilled needs in the oceanographic research and prediction fields. Oceanographic models currently employ only boundary conditions and external forcing fields to drive internal model processes. For many years this has been regarded as a deficiency in ocean modeling: how can the internal mechanisms be best represented when *in-situ* data is largely unavailable? A system such as ARGO will provide a significant amount of *in-situ* data, supplementing the current

boundary conditions and forcing fields, thereby greatly increasing the capabilities of any ocean model.

The concept of ARGO is twofold: develop an observational platform that can effectively observe ocean conditions at various depths and report them to a data collection center in a timely fashion, and implement enough of these platforms around the world to generate a comprehensive view of the world's oceans. The first portion of this venture has been accomplished through recent advances in autonomous data collection devices and the improvements in satellite communications. Where just a few years ago data would be recorded on a medium housed inside the observation platform, then require retrieval to allow scientists access to the data, now real time transmission of observational data is possible through communication satellites, and virtually instantaneous downloads of data from sources around the world is commonplace.

These advances have already provided great benefits for scientists and society. The use of moored buoys and drifting buoys have greatly improved the ability to ascertain the conditions in remote portions of the ocean, then use this knowledge to analyze and predict what processes are occurring. An excellent example of this is the ENSO observing system. This system consists of a combination of moored buoys, drifting buoys, and expendable bathythermographs that allow for close observation of the tropical Pacific Ocean for signs of impending El Niño/ La Niña events. The buoys used for this type of data collection transmit their data via satellites to provide continuous and timely conditions of this area throughout the year.

ARGO combines the ability to transmit data from around the world with recent developments in autonomous floats to provide a mechanism for observing the upper

ocean. Previously deep ocean observations were accomplished via two methods: (CTD) sensors, and bathythermographs of various types, including (XBT). These two relied on the presence of a ship in the area to attend to the instrument (CTD) or at least release the instrument and collect the data (XBT). ARGO floats take the technology devised in the development of the CTD and apply it to an autonomous system.

2. ARGO Design

The design for the ARGO float (Figure 1) allows for preprogramming of depths, data collection periods, and ease of deployment. The ARGO float consists of four major parts: the buoyancy control system, the data collection system, the data transmission system, and a control system to direct and monitor the other three systems. The buoyancy control system regulates the depth at which the float will reside, through the use of pressure sensors, hydraulic and pneumatic pumps, and multiple bladders. A temperature/conductivity sensor outside the main compartment of the float collects data as the float comes to the surface. The data is then transmitted by the external antenna and internal transmitter package. The onboard batteries allow for up to 100 collections and transmissions of data, and can be replaced, extending the life cycles of the instruments to indefinite periods.

The task for ARGO is to reside at depth for a preprogrammed amount of time, then rise to the surface, taking observations of temperature and conductivity (salinity) at specified depths. The float then transmits this data and its location to satellites overhead, and subsequently returns to the programmed depth to wait for the next observation time (Figure 2). ARGO has put forward specifications for the floats: a resident depth of 1000 meters, and a 10-day observation cycle, which would allow for a single float to provide

data for up to 1000 days or more (3+ years). The current technology level of autonomous floats includes an accuracy of 0.01°C for temperature readings and salinity measurements accurate to 0.01 Practical Salinity Unit (PSU). The goal of ARGO is to have 3000 floats operating throughout the world by the year 2005. This size of endeavor will provide scientists and researchers with approximately 10,000 observations per month. This number is an astronomical gain in ocean profile data since the World Ocean Circulation Experiment (WOCE) collected 9,000 CTD and 40,000 XBT observations over a period of nine years, the same amount that had been collected for the rest of the century! The huge benefits of autonomous data collection begin to become evident when numbers such as these are considered.

This system of autonomous floats will provide GODAE with the *in-situ* data source so very vital to complement remote sensing data collected by satellites. The combinations of these forms of data are becoming more and more evident. Every day researchers are looking at combining the altimetry data from satellites and the profile data from ARGO floats to provide a completely new view of the ocean, its conditions, and its processes.

C. NAVY OPERATIONAL GLOBAL ATMOSPHERIC PREDICTION SYSTEM

Fleet Numerical uses the Navy Operational Global Atmospheric Prediction System (NOGAPS) as a global meteorological numerical model. This model uses 24 sigma levels, from the earth's surface up to 10 millibars, to provide a complete view of the conditions in the atmosphere (Table 2). The numerical model is hydrostatic, and uses spectral wave analysis to discern atmospheric conditions. The output resolution of the

model is one degree (latitude and longitude), roughly 81 km at mid latitudes. This model provides geopotential heights, winds, temperatures, dew point temperatures, heat flux and wind forcing parameters. This source matches the requirements for GODAE to pull meteorological model output to supplement the oceanographic data sets accumulated. This is particularly useful due to the fact that Fleet Numerical uses the results from NOGAPS to provide forcing fields to several other models, including wave models such as the Global Wave Model (GWAM), Wave Watch 3 (WW3), and regional meteorological models such as the Coupled Oceanographic and Atmospheric Mesoscale Prediction System (COAMPS) (Table 3).

D. WESTERN PACIFIC CHARACTERISTICS AND THE KUROSHIO CURRENT

The Northwest Pacific area, specifically the area around Japan and the Kuroshio current, is an appropriate choice for study pertaining to GODAE for many reasons. This area is the focus of significant interest in regards to understanding ocean dynamics and improving the ability to predict ocean conditions. The heavy shipping traffic both into and out from Japan, large fisheries and the associated industries, and weather effects from changing current paths are just some of the areas of influence of the Kuroshio. The area is also of high importance to U.S. Naval Ships, and increased knowledge about the conditions of this area of the Pacific would greatly increase the safety of U.S. Naval forces operating in the area. This area's proximity to Japan, a member country of the GODAE project, and the possible benefits that would come from an increase in the *in-situ* data collected in this area, make it a likely location for significant future research and

effort in applying the resulting information from GODAE to new and innovative oceanographic research.

The Kuroshio Current is a western boundary current that makes up the western portion of the North Pacific Ocean gyre. One of the largest currents in the world by volume, this current is similar in many respects to the Gulf Stream on the east coast of the United States. The majority of water that makes up the Kuroshio Current comes from the Northern Pacific Equatorial Current. The Kuroshio originates east of the Philippine Islands, travels east of Taiwan, follows a varied path through the East China Sea, turns east through the Tokara Strait, south of the island of Kyushu. The current follows the eastern side of the islands of Shikoku and Honshu, then turns east where it becomes the Kuroshio Current Extension. This path is not static, with meanders along much of the current's path changing throughout the year. The path of the Kuroshio follows three basic patterns when passing the islands of Shokiku and Honshu. These different paths of meanders vary from near the coast to hundreds of kilometers offshore. The path changes occur at irregular intervals, with changes between the paths closer to shore occurring more often than large meanders in the current (Figure 3). The proximity of the Izu Ridge to this area of changing meanders may have some significant effects on this phenomenon, but to date no definitive temporal pattern to the changing meanders has been developed.

III. DATA

Data availability and utility from the USGODAE servers is the ultimate test of the viability of this project. The data inputs required to compile a comprehensive and reliable data set are enormous. Much attention must be paid to this aspect of GODAE to ensure success. Without successfully providing data in a timely and routine fashion, GODAE will likely not meet its goals.

A. DATA SELECTION PROCESS

1. Data Types

A single type of data on the server needed to be chosen to assess GODAE's utility as an assimilation, storage, and dissemination point for oceanographic data. This sample data type would have to come from the data sets currently available on the USGODAE server:

- <u>Altimetry:</u> Altimetry data is gathered from TOPEX and ERS Sea Surface Height Averages (SSHA). Available in Institute of Electrical and Electronics Engineers (IEEE) format via both Hyper Text Transfer Protocol (HTTP) and File Transfer Protocol (FTP).
- <u>Muti-Channel Sea Surface Temperature (MCSST):</u> Sea surface temperature is gathered from the Advanced Very High Resolution Radiometer (AVHRR). Available in IEEE format via both HTTP and FTP.
- <u>Ocean Profile:</u> Subsurface measures of *in-situ* temperature and salinity. These observations come from a wide variety of sources, and will be discussed further below. Available in IEEE format via both HTTP and FTP.

- Surface Observations: This data type consists of *in-situ* observations of surface conditions. Available in IEEE format via both HTTP and FTP.

- Special Sensor Microwave/ Ice (SSM/I): This data consists of ice edge data gathered from Defense Meteorological Satellite Program (DMSP) satellites. Available in IEEE format via both HTTP and FTP.

- Naval Oceanographic Office (NAVO) SST: SST analysis from NAVO models. Available in IEEE format via both in HTTP and FTP.

- Aircraft Reports: These observations include Aeronautical Radio Incorporated (ARINC) Communications Addressing and Reporting System (ACARS), Upper Air Reports (AIREPS).

- Upper Air Observations: Observations include piloted balloons (PIBALS) and rawinsondes (RAOB).

- Land Observations: Include land observations and METAR data.

- Surface Observations: Surface ship observations and buoy observations are included in this section.

- Satellite Observations: This section includes Satellite Derived Observation Reports (SATOBS), Satellite Feature Tracked Wind Reports (SAFTW), Scatterometer Reports, SSM/I, Special Sensor Microwave/ Temperature (SSM/T), SSM/T2 (humidity), and Television Infrared Observational Satellite (TIROS) Operational Vertical Sounder (TOVS).

- NOGAPS: This model and its output are described in (Table 1).

- COAMPS: The parameters and output for this model are described in (Table 2).

2. Selection Criteria

When assessing these types of data for applicability in use for this thesis, several basic factors were considered:

- Does the data type relate directly to ocean conditions and oceanographic research?
- Is the type of data one that is vital to the success of the GODAE project?
- Is the data in a format that can be readily processed?
- Is the data of a magnitude that can be processed with the resources available?
- Does the data have significant promise in future oceanographic research?

The first criterion greatly narrowed the types of data to be considered. All meteorological data, both observational and model output, was eliminated to focus directly on oceanographic parameters. This was done to ensure that the topic of this thesis would remain germane to the original goal of assessing the GODAE oceanographic data and measuring the utility in a real world endeavor. The second criterion served as a method of eliminating the possibility of choosing a data type that may not be fully implemented in the GODAE plan and therefore be rendered insignificant in regards to this thesis topic. The emphasis of this thesis is to evaluate data that will likely be available for several years to increase the possibility of continuation of this type of work. The third criterion ensured that selection of a data type would not end in an unsuccessful attempt to process, view, and assess the data for utility and feasibility. Although all data types were usable in some form, processing and formatting issues were addressed to ensure successful data retrieval for assessment. The fourth criterion was one of size: the

choice of data depended on the availability of disk space for retrieval and processing. Although several data sources met this standard, some would have proven much too large to ingest and process into a viable product without significant resources. The final criterion is one of some significant subjective estimation. Although it is likely that all forms of data will be important in understanding the ocean, its condition, and processes, care was taken to choose a data type that will likely be relevant for years to come.

The ocean profile observation, specifically observations from autonomous drifting observation platforms (i.e., ARGO), was chosen for its qualification under all of these criteria, and also because it is a new and still developing system. ARGO, as described earlier, is still under development and has only been implemented in a limited level. The potential for an observation system such as this is immense, and could likely change the way that oceanographic modeling is pursued for many years. GODAE uses this type of data as a cornerstone for its development as a complete view of oceanic conditions. As a result, profiles collected by drifting platforms, such as ARGO, have been selected as the data for assessment.

B. DATA RETRIEVAL AND PROCESSING

1. Data Retrieval

The initial process of retrieving ocean profile data from the GODAE server reflects one of the guiding principles of the GODAE project: open and readily accessible oceanographic data by various research groups. The ocean profile data is available by either FTP or HTTP. File size ranged from 200-300Kb per day of data. The current archive of profile data has daily files beginning with 1 September 2000 and continues up to present time. These data files are updated twice daily, so an expected time delay of

approximately 12 hours exists for near-real time data. These files are stored in a compressed state, and in IEEE format. The time window of the data selected for processing and visualization was 1 September 2000 to 8 March 2001. This time period was selected to provide a data set that would allow for a basic assessment, but not surpass the data storage and processing capabilities allocated. The end of this time period was selected to facilitate completion of a single data set for processing, visualization, and assessment.

2. Data Processing

Consideration of the visualization method is imperative in determining data format, file size, and storage methods, and when processing retrieved profile data. The initial method selected to visualize this profile data was Ferret, an interactive visualization and analysis environment used at other institutions such as the National Oceanic and Atmospheric Administration (NOAA) Pacific Marine Environmental Labs (PMEL). This software was initially chosen because of the implied ease of developing visualization products and preceding use in the visualization of meteorological and oceanographic products.

Attempts to use Ferret were met with less than complete success. Differences in data formats, initial startup time in developing the visualization code necessary to provide the required results, and software support were factors in reevaluating the visualization method. The second method chosen for visualization was Matlab. This choice proved much more successful due to familiarity with the language, significant local software support, and data format conversion methods.

The visualization method choice allowed for initial processing of data to convert the data from the format of the GODAE files (compressed IEEE) to a format that would be easily read by Matlab. The USGODAE server supplies FORTRAN 77 source code for a script that facilitates the transfer of data from IEEE to American Standard Code for Information Interchange (ASCII) format. This source code also comes with a supplemental file that lists all available ocean profile data types (Table 4). The observation list file is read by the executable file to compile a listing of available ocean observation data types for use in conversion to ASCII format. The source code was compiled and the files converted to ASCII format.

The resultant file is a text record of all ocean profiles collected and archived on the USGODAE server for that day (Figure 4). The format of the file allows for each observation to be viewed separately, with each observation entered as a separate entry. Each file begins with a header that reports the Date-Time Group (DTG) of the observation data, the directory in which the file was stored on the GODAE server, the number of profiles in that day of the archive, and the maximum number of reporting levels for all of the profiles for that day. The data for each profile entry is preceded by a header that provides all pertinent information for that profile: the call sign of the reporting entity; the latitude and longitude for the data collection point; the date and time that the data was collected; as well as a second data and time for when the data was transmitted (to account for any delays); the bottom depth for that location; the data type code; the corresponding text representation for that data type; the number of observed levels; the number of observed temperature levels; the number of observed salinity levels; the gross errors for temperature and salinity; the sea surface height anomaly and

temperature; and the classification of the observation. For the record, no observation was found with a classification other than "U," and all were assumed to be unclassified. The data provided was in column form, and consisted of depth (measured in meters), temp (temperature, in °C), salt (salinity, in PSU), temp_std (temperature, standard deviation), sal_std (salinity, standard deviation), temp_prob (temperature gross probability of error), sal_prob (salinity gross probability of error), clim (temperature derived from climatological data from the Generalized Digital Environmental Model (GDEM)), modas (temperature data from the Modular Ocean Data Assimilation System (MODAS)), glbl,(future global data field) and regn (future regional data field).

Upon inspection of the resultant ASCII formatted data, additional processing was required to extract the desired observations from the single file format of the archived file and make each observation available independently. In assessing methods to implement ease of access to individual files, the selected method was to completely remove each observation from the archive file and store it as an individual file, with nomenclature designed for ease in organization and readily searchable. The file name format consists of the identification number of the instrument platform and the DTG of the observation. This allows for searches to be performed over specified time periods and for specific instrument platforms. Since the observations were going to be presented in a visual format, based upon location around the globe, location data for the observation (latitude and longitude) was not included in the naming convention.

The file created for each observation followed a precise format to aid in data accessibility by Matlab scripts. Each observation was searched for the desired instrument platform type, and the associated information was written to a file with that instrument

platform's identification number and the observation DTG. The new file contained the data recorded for depth, temperature, salinity, GDEM climatological temperature, latitude and longitude.

A supplemental file to assist in visualization consists of a listing of each observation in the data set. Each observation is listed with the instrument platform identification number, location (latitude and longitude), temperature recorded at the first observation level, and the observation DTG. The use of this file is discussed below.

C. DATA VISUALIZATION

Data visualization was implemented using Matlab, as mentioned in previous discussion. The visualization process had certain functionality requirements in order to be regarded as successful. These requirements involved the ability to search for specific subsets of data, visually separate specific groups of observations, and view graphical representations of temperature (T), salinity (S), climatology, and temperature-salinity (T/S).

The visualization application uses a world map as the initial figure of reference (Figure 5). The user can use the entire globe, or zoom in using the appropriate function button on the toolbar (Figure 6).

The ability to search for specific subsets of observations was greatly aided by the use of the identification number/ observation DTG file naming convention. This allowed the Matlab application to search the supplemental file for a particular identification number or time period, return the appropriate observations, and display the requested observations. The Matlab script allows the user to search for a specific month of data by choosing that function from the toolbar, then choosing the desired month from the list of

available data months (Figure 7). The locations of the selected observations are shown on the figure. The same method can be used to select a specific day of data, a specific instrument platform, or a combination of these parameters. These subsets of data can be differentiated by selecting different colors for the subsequent data subset to be shown (Figure 8). The figure can be reset to remove all the previously shown data

Graphical representations of data for specific observations can be generated using the previously selected data sets as a guide. Selecting the type of profile desired from the toolbar (Figure 9) initiates a function that will follow the user's cursor across the displayed map area, highlighting the nearest observation to the cursor location on the map, and showing a new window with information for that observation. This information is to assist the user in identifying the desired observation correctly to produce the corresponding profile. The data for each observation provides the identification number, DTG of the observation, latitude, longitude, and SST (Figure 10). Using this information, the user can narrow down even a large group of observations to a single data point for analysis. When the user selects the data point, a new window appears with the desired profile. This comes complete with axis labels and appropriate designation of the observation DTG and identification number. Each of these images can be stored in a variety of formats, including JPEG (.jpg) and Compuserve Graphical Interface Format (.gif).

THIS PAGE INTENTIONALLY LEFT BLANK

IV. RESULTS

A. DATA UTILITY

The USGODAE server provided is an excellent source of easily downloadable data and minimizes many difficulties associated with accessing and retrieving quality oceanographic data. The data processing portion of this thesis encountered some difficulty with the aforementioned visualization tool choices. The initial choice to use Ferret as the graphics package of choice included several hurdles regarding data processing and formatting that added to the difficulty of implementing Ferret successfully. The unfamiliarity with Ferret led to difficulty in ascertaining the correct process for data formatting, and resulted in significant amounts of time invested in researching data formatting options. The resultant choice to move to Matlab for graphics generation significantly simplified the process of producing a data set in a compatible format. Data visualization was successful with the combined efforts of the Oceanography department and significant software support.

The data set used for visualization totaled over 6200 observations covering a time period of just over six months. The time periods between observations varied from 12 hours to approximately 10 days. The depth of measurement for the group of observation platforms ranged from 200 to 2,000 m. This difference is attributed to two likely causes. Each country that purchases observation platforms has some influence in determining the parameters preprogrammed in each system. The variance in data levels and time periods can also be attributed to other types of regularly scheduled observations being organized in the same category as the data type chosen. The variance in data depth ranges and

observation time periods was ignored as statistical assessment of the data was not involved and the variances did not affect the goal of assessing the feasibility of data use.

Data concentration in the Northwest Pacific Ocean, namely in the Kuroshio Current and in the Sea of Japan, was the driving force in the selection of that area of the Pacific for further scrutiny (Figure 11). A single buoy was selected from the area surrounding Japan to provide examples of temperature, salinity, and gross velocity for that area. A second buoy in the Eastern Pacific was also chosen to assess differences in data from different instrument platforms that may be discernable from visual assessment of the data. The following is an overview of the results of data visualization efforts.

B. OCEAN PROFILE DATA

1. Temperature

Temperature data was readily available and comprised the majority of data assessment for the Pacific Ocean portion of the data set. Upon inspection of the initial profiles of temperature, the data showed expected temperature ranges for that area. The observation recorded for buoy 21856 for 4 September 2000 was indicative of the results for the region. SST for this observation was 21.5° Centigrade, with a steep decline in the first few meters to less than 5° C (Figure 12). The location for this observation was north of the 35th parallel, the usual location for the Kuroshio's sharp turn to the east and subsequent meanders. The temperature profile depicts a shallow sound channel from approximately 20 to 80 m, and another deeper sound channel from 100 to 400 m. After initial assessment of the profile, the data from the observation platform was found to stop well before the 5,000 m mark, which is shown in the temperature profile. Upon further

investigation, the discrepancy was attributed to climatology data that was added to the observational data to provide data to a continuous depth level for all observations. This discovery was supported by the mention of "temperature levels" in the header information attached to the original data file and discussions with data management personnel for the USGODAE server. The profile of temperature (observed) and temperature (climatology) also supports this visually (Figure 13), and comparison of raw data values for the observed and climatology temperatures matched after 1500m.

The observation from buoy 32636 for 6 September 2000 was chosen for comparison to determine if the temperature data was supplemented with climatology for this platform, as in the previous example. Use of climatological data to supplement observed temperature levels was evident in this ocean profile (Figure 14). Comparison of raw data values also showed matching values for the observed and climatology values at depths greater that 2000m.

2. Salinity

Salinity values for the data set were scrutinized to determine if the data recorded was from observed conditions in the ocean or supplemented with climatology, as in the case of temperature measurements. Initial assessment of the ocean profiles did not assist in comparison with a data set of climatological salinity was not included in the observational data. Examination of the header information of several observations showed consistent "salinity levels" values of zero. Discussion with USGODAE server data support personnel supported the conclusion that the salinity for observations with a zero value for "salinity levels" was in fact climatology. Observations for buoy 21856 and

32656 showed zero salinity levels reported, hence all data for these buoys are substituted climatological data.

3. Gross Velocity

Gross velocity in this case is defined as the distance between two observations divided by the time between observations. This method of determining velocity gives a general estimation for the movement of the observational platform, and does not take into account velocity change with regard to position in the ocean column.

Buoy 21856 was assessed to determine estimates for gross velocity. Using the latitude and longitude values given with each observation, values for gross velocity ranged from 0.2 m/s to 3.9 m/s. The variation in velocity is supported in the differing distances between observations shown for buoy number 21856 (Figure 10).

V. CONCLUSIONS

A. DATA RETRIEVAL AND PROCESSING

The data retrieval from the USGODAE server was a direct and efficient process. The availability of data in IEEE provides a common format that is compatible with many different applications. The software provided on the USGODAE site to convert the data from IEEE to ASCII allows for even greater latitude in data application, and greatly simplified the processing time required to ingest the data into a Matlab visualization tool.

Data processing largely depends on the intended use envisioned by the user. The process by which the ASCII formatted data was parsed into files for use with Matlab was developed for this individual thesis, but similar manipulations of the data for alternative uses can be forseen and likely undertaken with high probabilities of success.

Early determination of the data content, with particular notice of observed data and climatological data sets, would provide for greater ability in determining the best use of the data and what, if any, subsequent processing would be required to achieve the desired data set. The supplementation of the observed data with climatological data was one not envisioned when the data was initially assessed. The subsequent results are a direct reflection of the need for a complete initial investigation of the data, and thorough documentation of the data included in the observation records.

B. DATA VISUALIZATION

The visualization of the ocean profile data set met the initial goals. The ability to separate the data into subsets by time and individual observation platforms made data visualization much more useful, and inclusion of different colors and the ability to overlay subsets on top of each other greatly aided in visually depicting the path taken by

an observing platform that is not moored. The profile selection function was helpful, especially the cursor-driven selection tool that displayed information about an observation before actual selection by the user. The choices of temperature, salinity, temperature/climatology, and temperature/salinity diagrams were appropriate for this data set, and proved insightful when determining the observational data and climatological data substitution situation previously discussed.

C. RECOMMENDATIONS FOR FUTURE STUDY

Future research utilizing GODAE data may include analysis of ocean conditions in comparison to climatological data currently available, comparison of operational ocean models with *in-situ* observations, or development of data validation and quality control schemes for incoming data to the GODAE servers. Assessment of ARGO data for accuracy, statistical analysis of *in-situ* data compared to climatological values, investigation of trends in ocean conditions, and observing changing long-term processes in the ocean as a result of human influence are but a few other areas for possible further study.

The possible opportunities for research stemming from GODAE are endless. If all the goals of GODAE are met and a comprehensive data source for the entire ocean is available in near-real time, the advances in oceanographic modeling will likely include better initialization fields for models, higher order equations implemented and validated with actual *in-situ* data, and real-time analysis of oceanic conditions. It is these advances and others not even conceived of yet that will provide the final assessment for GODAE.

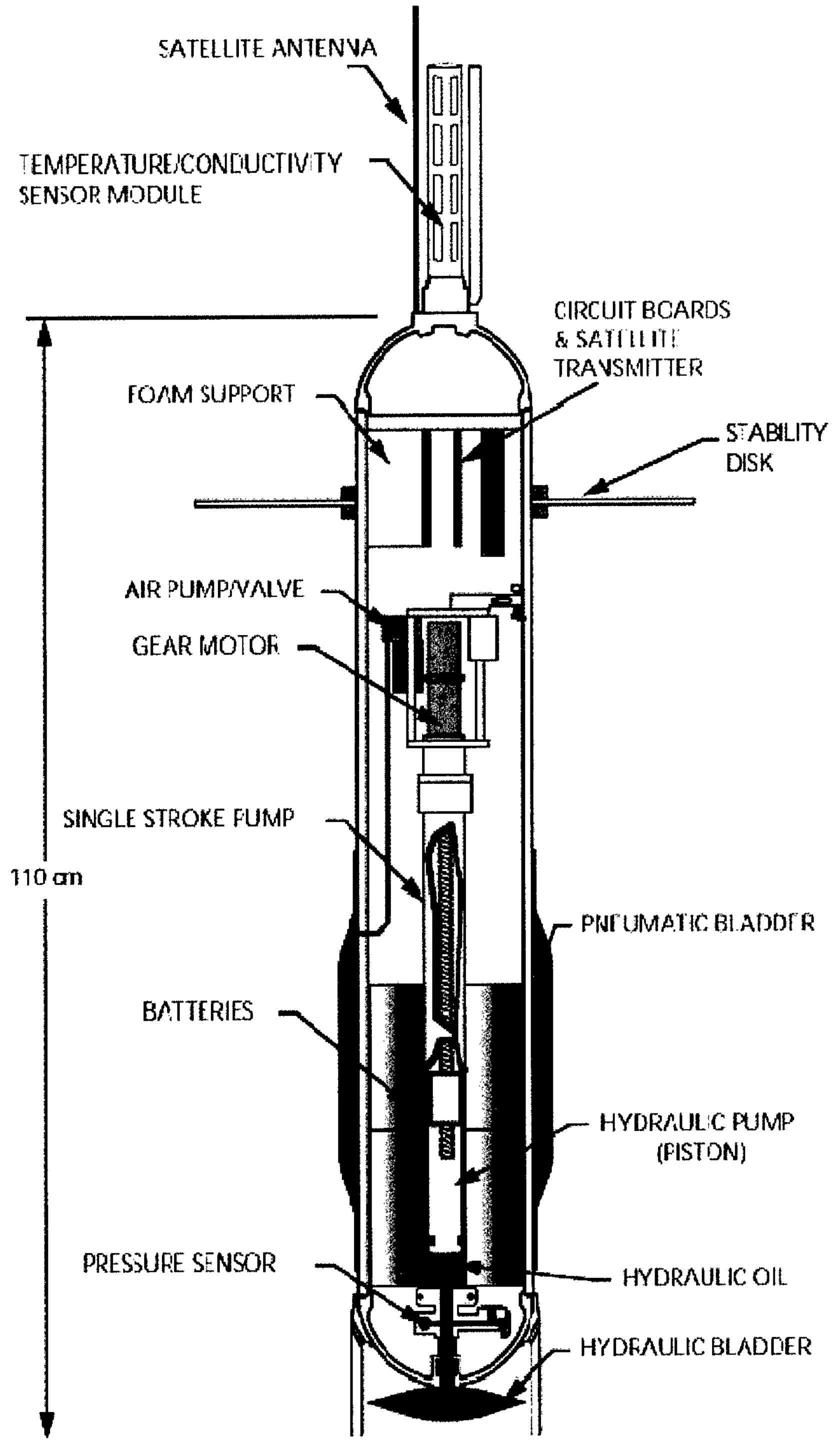

Figure 1: Schematic diagram of Array for Real-Time Geostrophic Oceanogrpahy (ARGO) float.

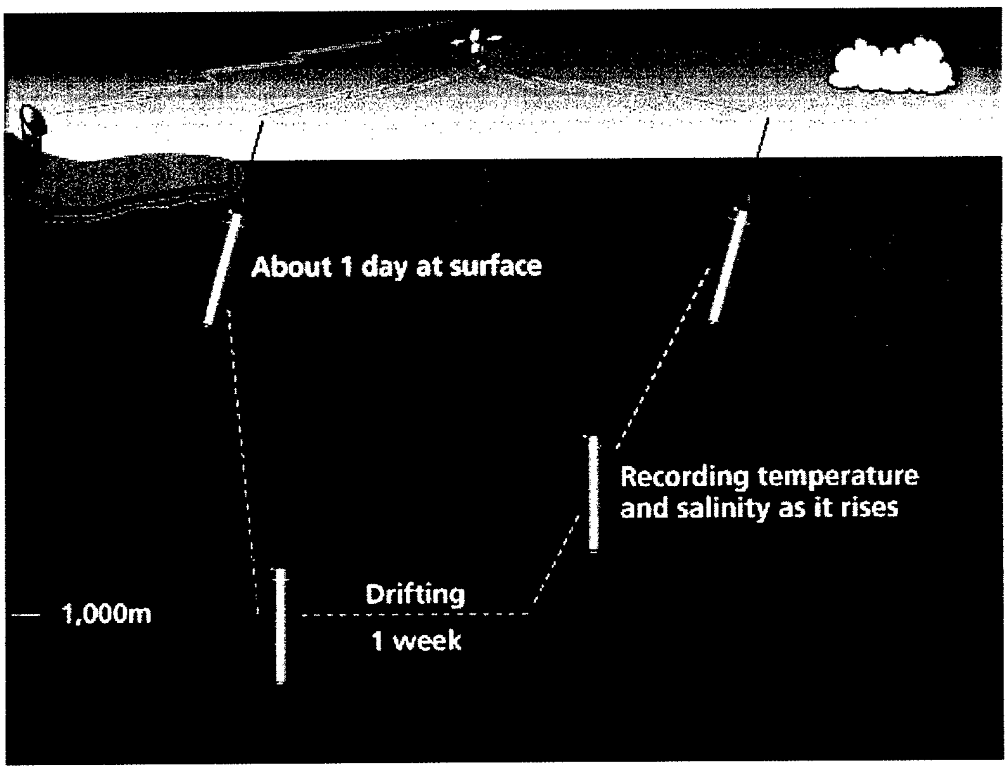

Figure 2: Graphical depiction of an ARGO float observation cycle (After Gwynne, 1999).

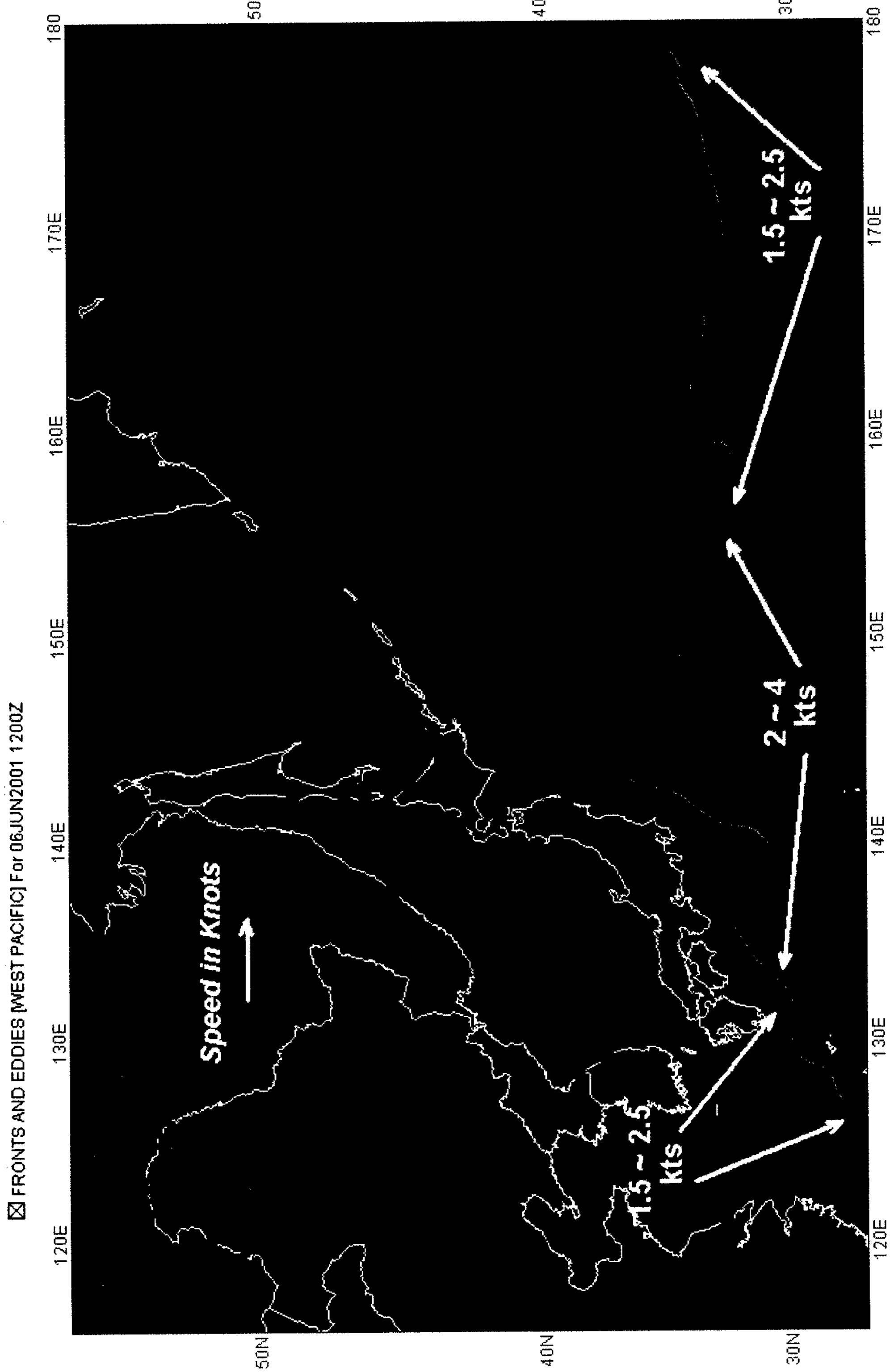

Figure 3. Depiction of the Kuroshio Current for June 8, 2001.

```
------------------------------------------------------------------------------------------------
profile call sign          : "62570  "
profile latitude           :     44.95
profile longitude          :     -22.12
profile observed DTG       : "200102191500"
profile received DTG       : "200102192020"
DBDB5 bottom depth         :     -999.0
profile data type code     :          5
profile data type          : "  Drifting BUOY"
total number levels        :          4
observed temperature levels :         4
observed salinity levels   :          0
temperature gross error    :     0.6977
salinity gross error       :     0.5747
sea surface height anomaly :  -999.0000
sea surface temperature    :      13.61
security classification    :        "U"
   depth   temp    salt  tmp_std  sal_std  tmp_prob  sal_prob   clim   modas    glbl     regn
     0.0  13.61   35.76     0.63     0.09    0.6647    0.4966  13.00   13.61  -999.00  -999.00
    20.0  13.55   35.76     0.62     0.09    0.6111    0.4763  13.02   13.60  -999.00  -999.00
    40.0  13.53   35.77     0.61     0.09    0.5935    0.4725  13.02   13.59  -999.00  -999.00
   180.0  13.50   35.80     0.55     0.09    0.8900    0.8011  12.62   13.17  -999.00  -999.00
------------------------------------------------------------------------------------------------
```

Figure 4: Example of ASCII output of ocean profile observation after conversion from IEEE format.

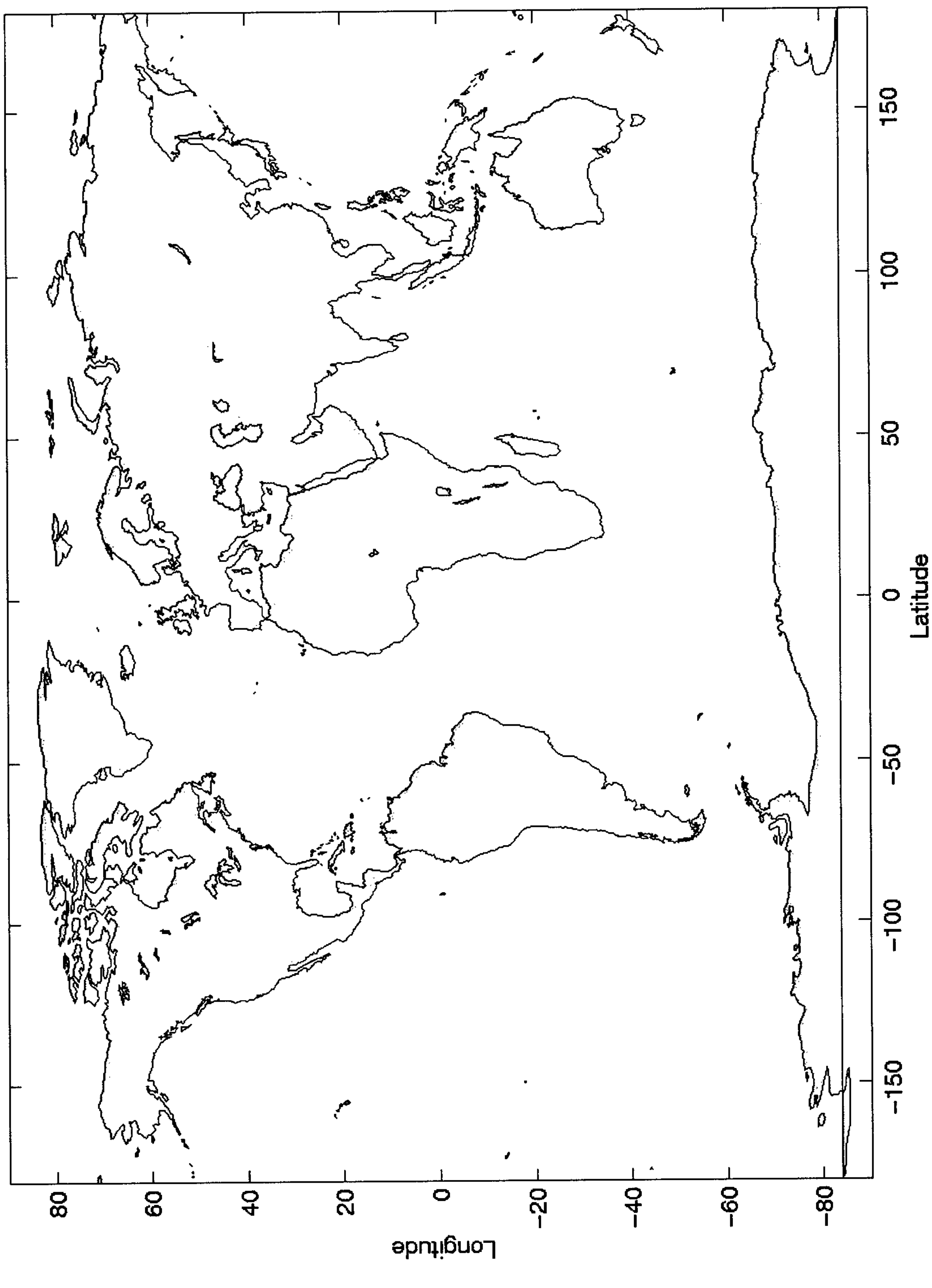

Figure 5: Template of geographical map used for locating ocean profile observations.

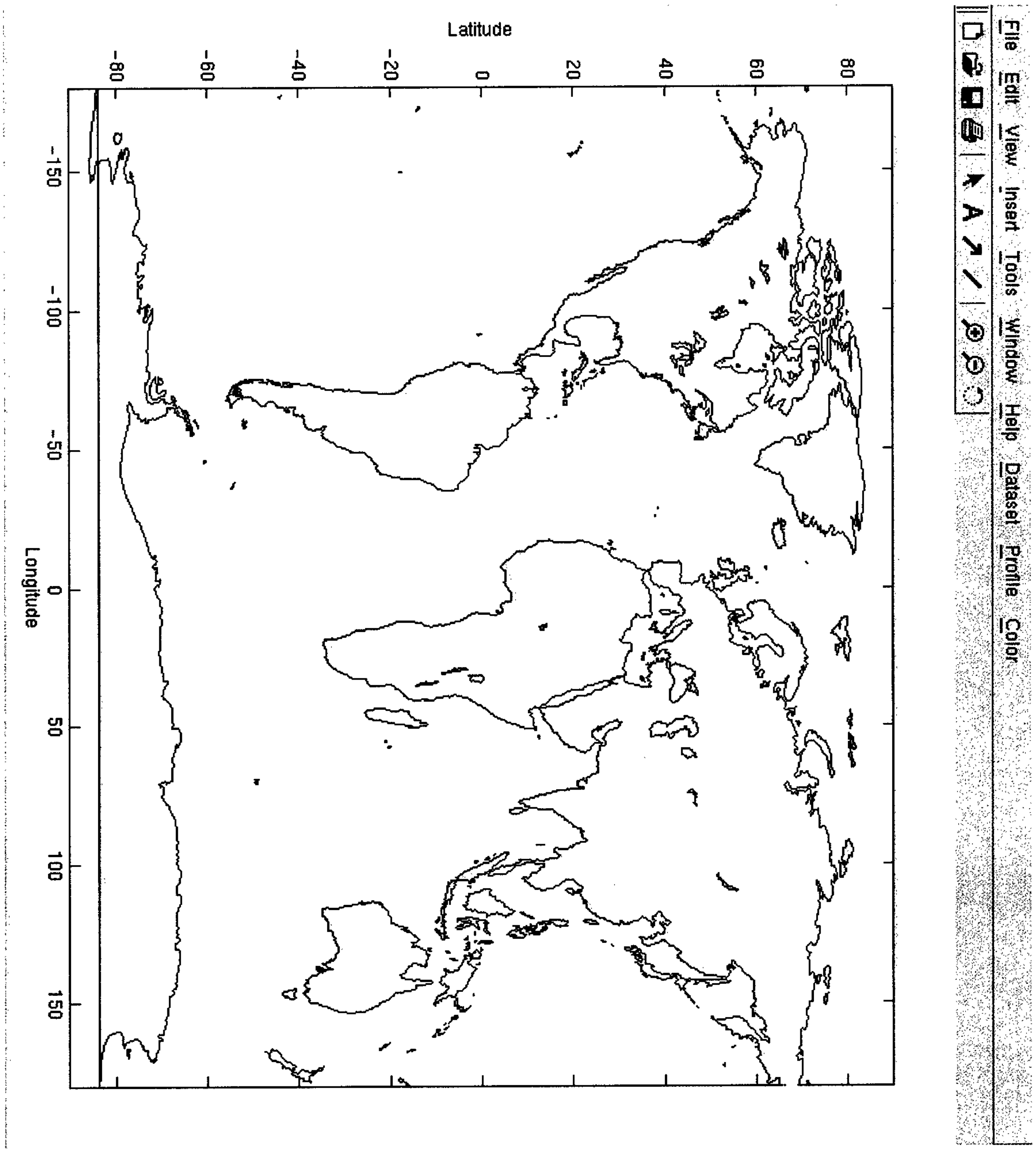

Figure 6: Example of map template with corresponding toolbar designed to facilitate data selection and depiction.

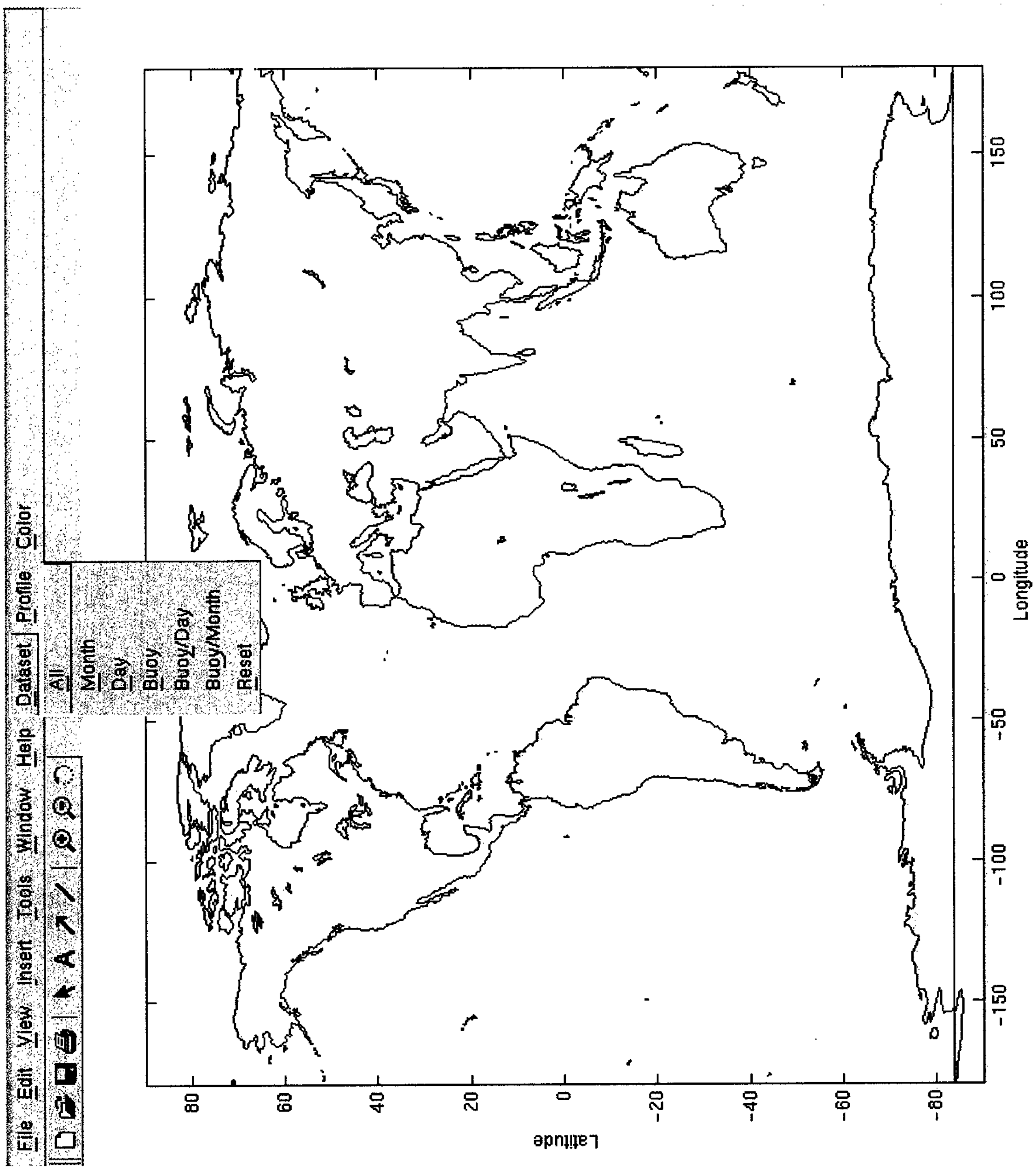

Figure 7: Display of data subset selection window providing multiple Time/Platform combinations.

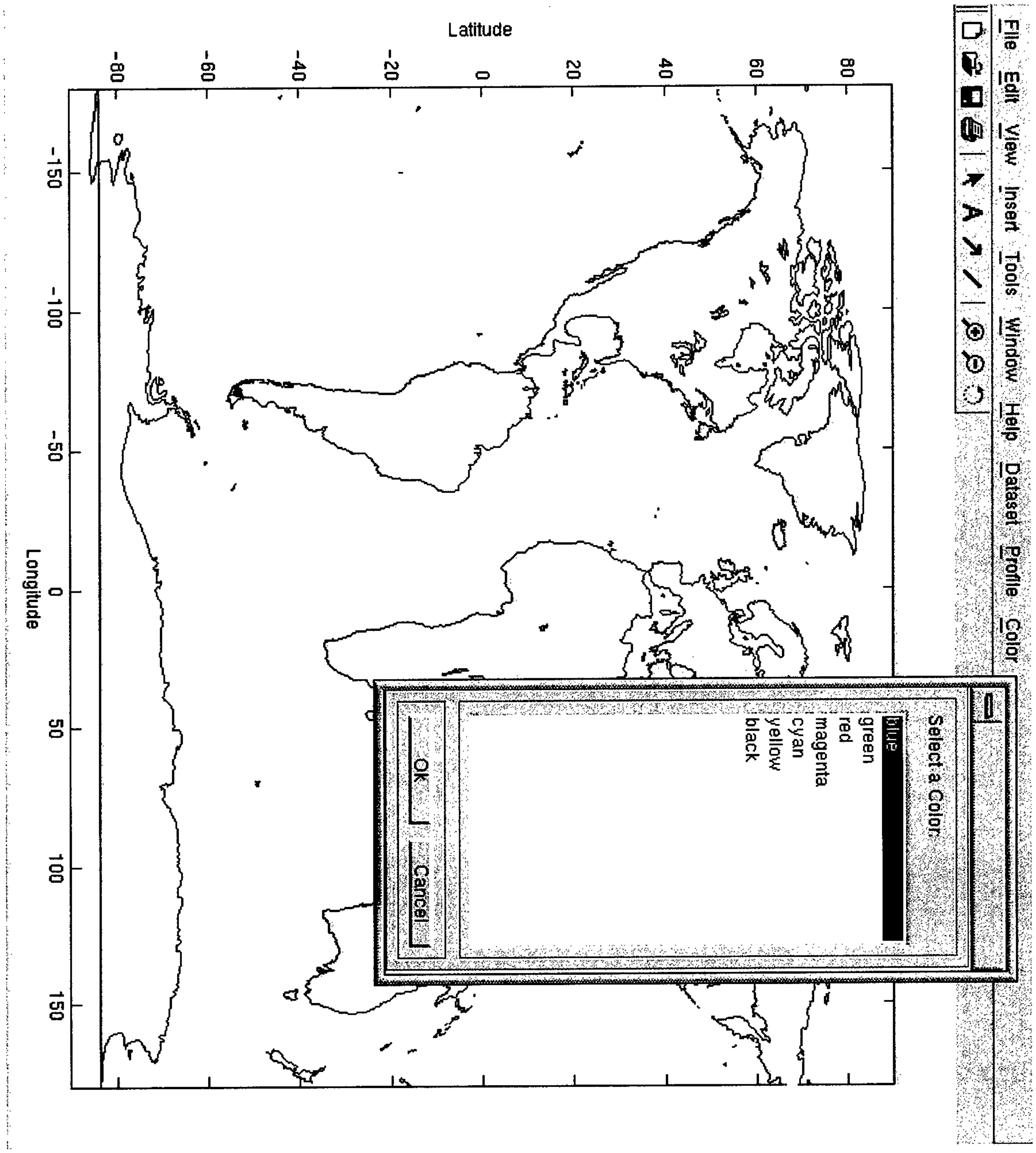

Figure 8: Display window depicting the Color Selection feature used to create visually discernable subsets.

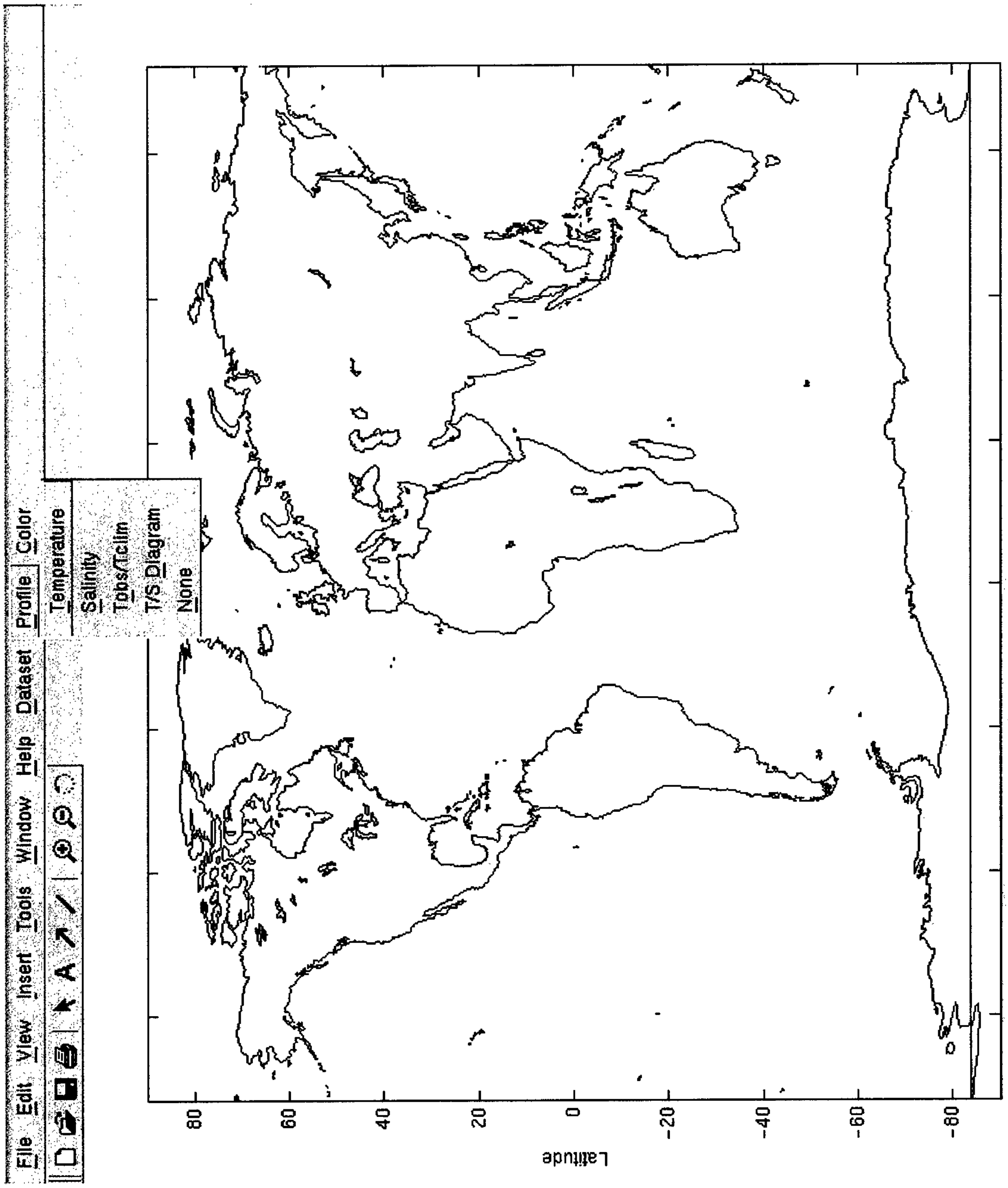

Figure 9: Display depicting the profile selection menu used for individual observation selection and generation of data profiles.

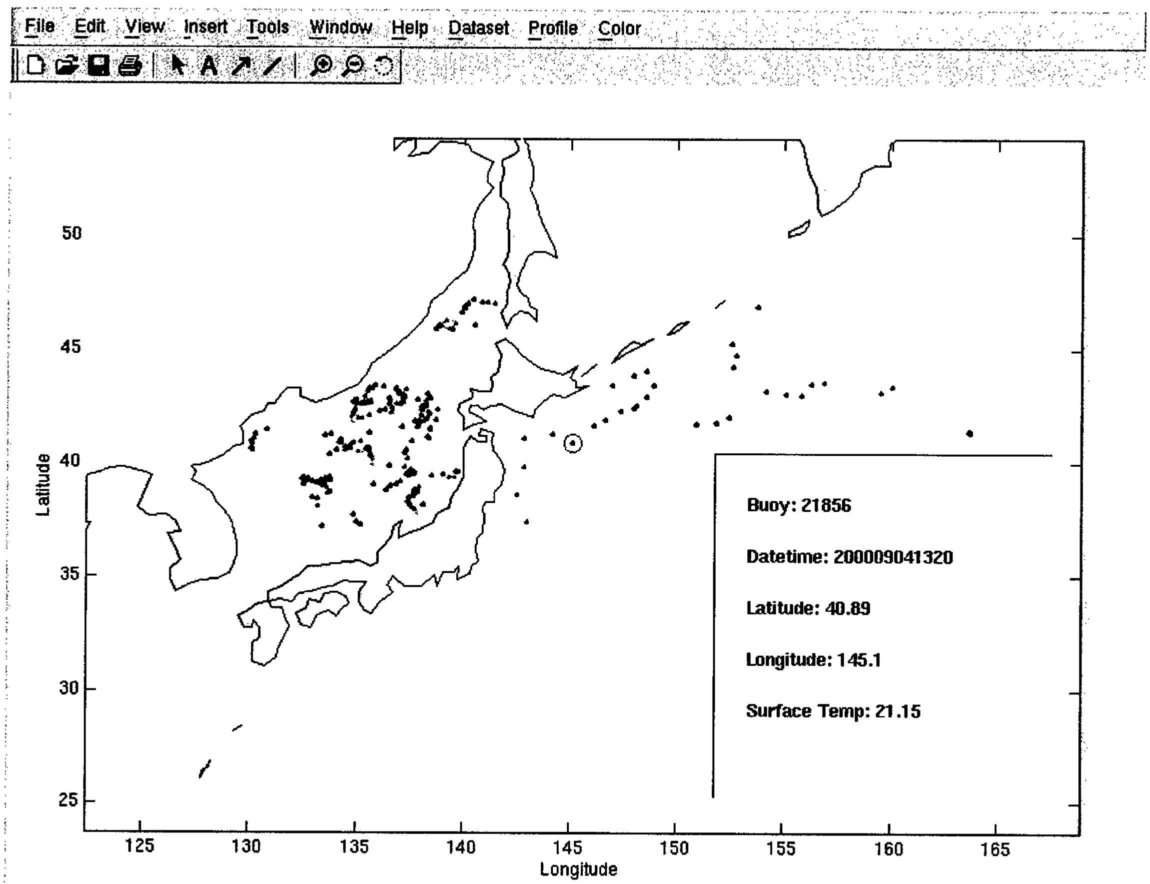

Figure 10: Display of Northwestern Pacific area with observation selection function enabled.

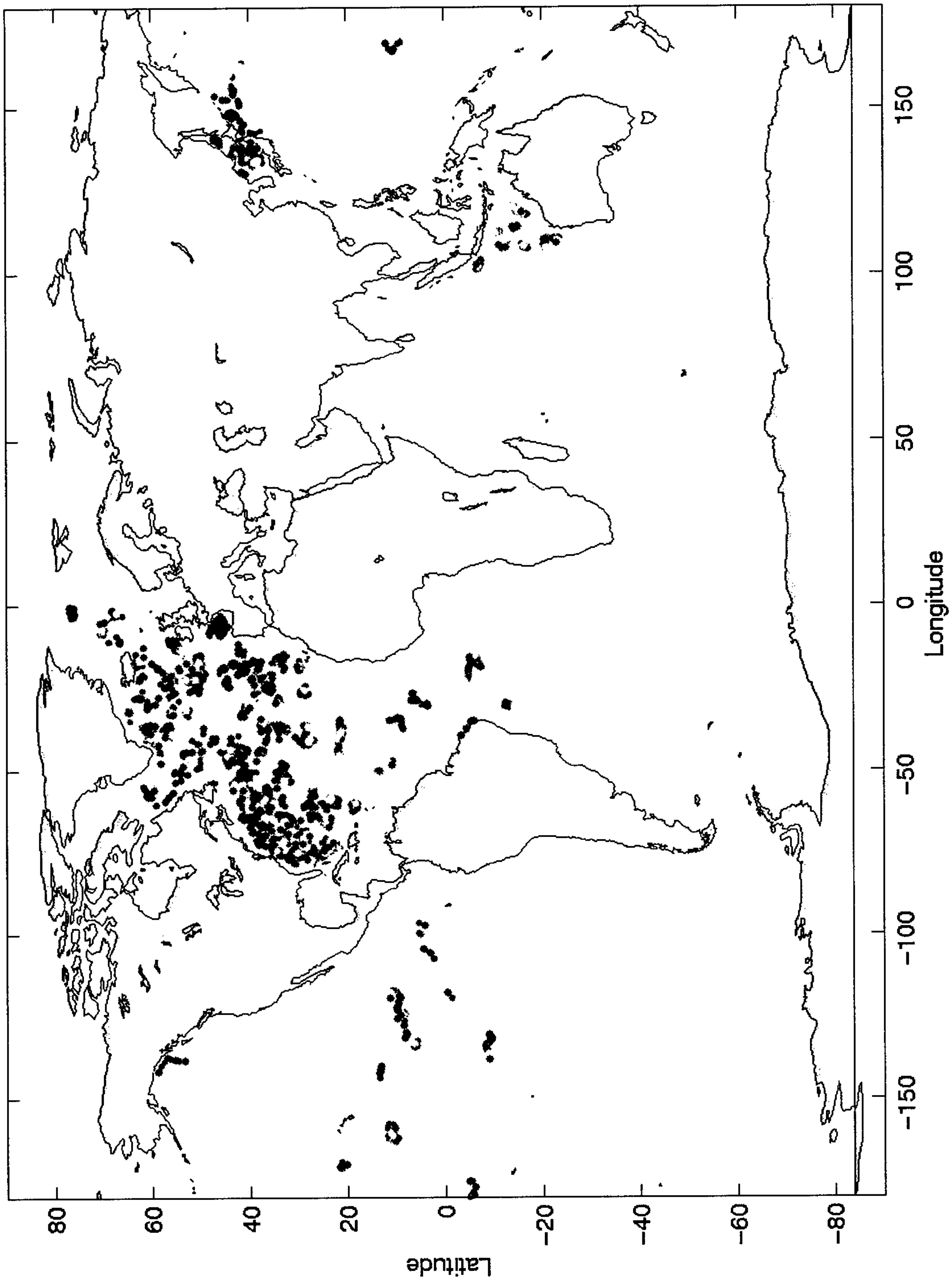

Figure 11: Depiction of world cumulative data points for ocean profile observations beginning September 1 2000 and ending March 8 2001.

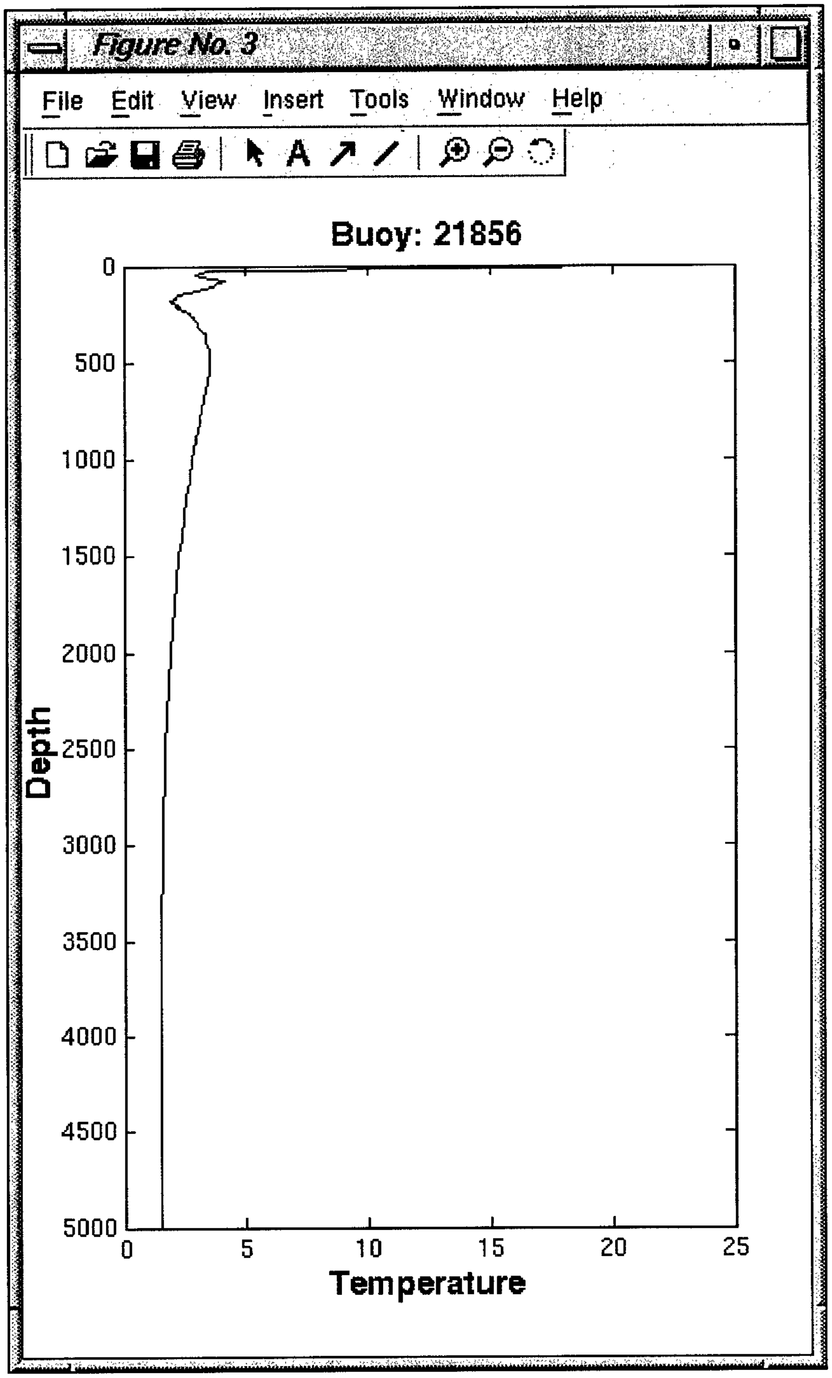

Figure 12: Temperature profile for buoy 21856. Observed at location 40.89°North, 145.1° West at 1320Z, September 4, 2000.

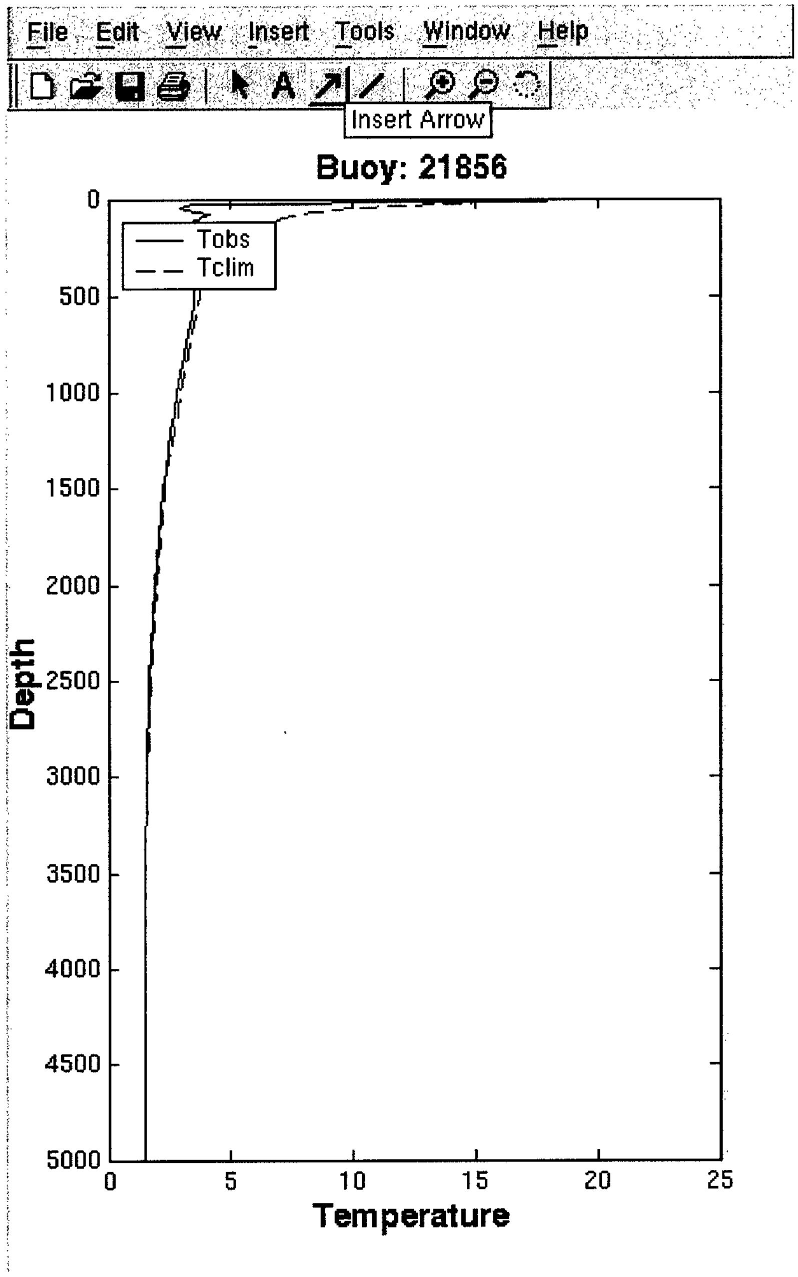

Figure 13: Ocean observation profile for buoy 21856 on September 4, 2000. Solid line represents temperature from observed data, and the dotted line represents climatology.

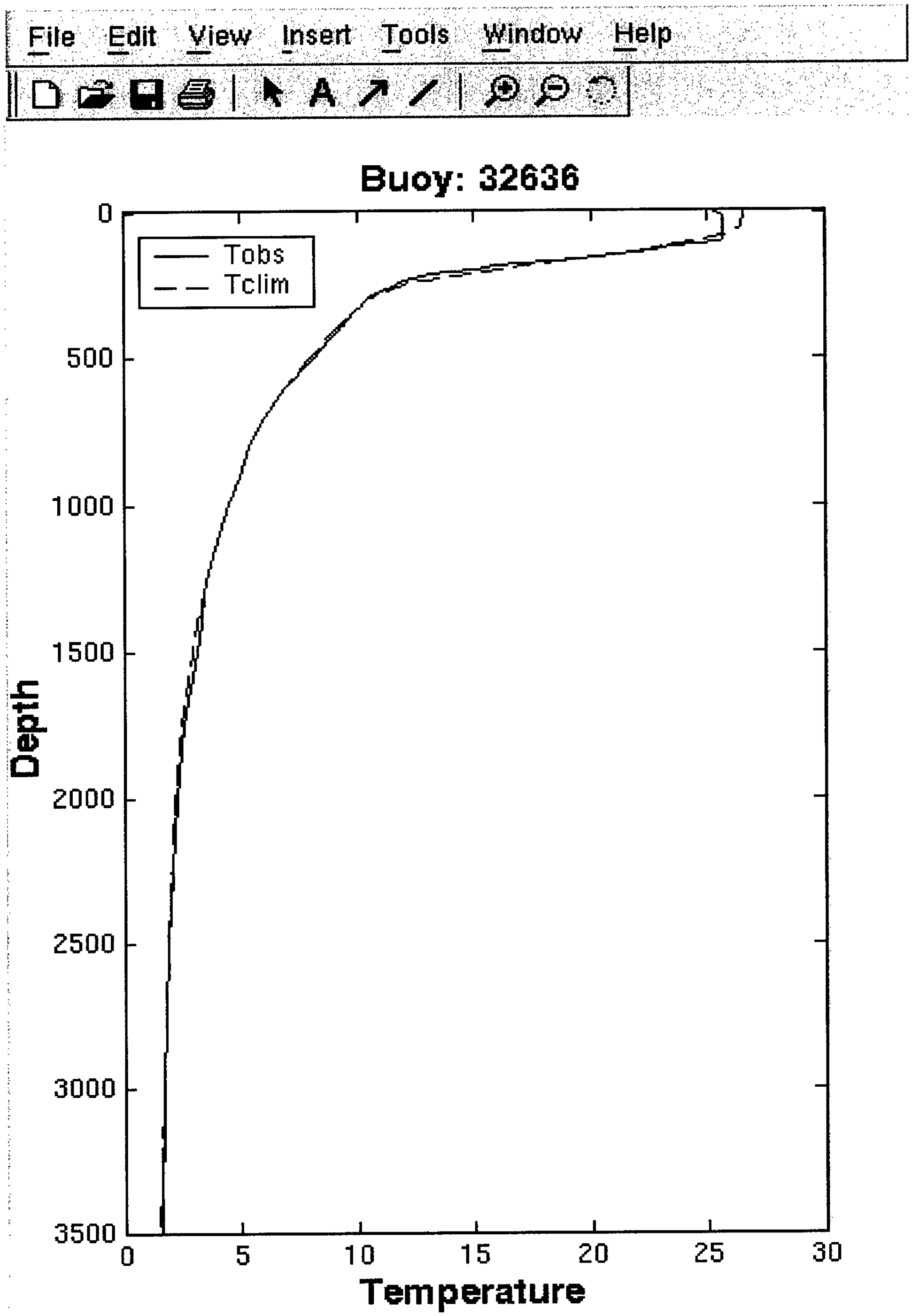

Figure 14: Ocean observation profile for buoy 32636 on September 6, 2000. Solid line represents temperature from observed data, and the dotted line represents climatology

Data Type	Description
Altimetry	Altimetry data is gathered from TOPEX and ERS Sea Surface Height Averages (SSHA). Available in Institute of Electrical and Electronics Engineers (IEEE) format via both HTTP and FTP
Muti-Channel Sea Surface Temperature (MCSST)	Sea surface temperature is gathered from the Advanced Very High Resolution Radiometer (AVHRR). Available in IEEE format via both HTTP and FTP
Ocean Profile	Subsurface measures of in-situ temperature and salinity. These observations come from a wide variety of sources, and will be discussed further below. Available in IEEE format via both HTTP and FTP
Surface Observations	In-situ observations of surface conditions. Available in IEEE format via both HTTP and FTP.
Special Sensor Microwave/ Ice (SSM/I)	This data consists of ice edge data gathered from Defense Meteorological Satellite Program (DMSP) satellites. Available in IEEE format via both HTTP and FTP.
Naval Oceanographic Office (NAVO) SST	Sea surface temperature analysis from NAVO models. Available in IEEE format via both in HTTP and FTP.
Aircraft Reports	These observations include Aeronautical Radio Incorporated (ARINC) Communications Addressing and Reporting System (ACARS), Upper Air Reports (AIREPS), AMDAR, MCDRS
Upper Air Observations	Observations include piloted balloons (PIBALS) and rawinsondes (RAOB)
Land Observations	Include land observations and METAR data
Surface Observations	Surface ship observations and buoy observations are included in this section.
Satellite Observations	Satellite Derived Observation Reports (SATOBS), Satellite Feature Tracked Wind Reports (SAFTW), Scatterometer Reports, SSM/I, Special Sensor Microwave/ Temperature (SSM/T), SSM/T2, and Television Infrared Observational Satellite (TIROS) Operational Vertical Sounder (TOVS).
NOGAPS	
COAMPS	

Table 1: Data types currently available on USGODAE server (After USGODAE web site).

Variables	Conditions
Basic equations	Primitive equations with hydrostatic approximation
Independent variables	Latitude, longitude, hybrid pressure coordinate, sigma levels
Dependent variables	Vorticity, divergence, virtual potential temperature, specific humidity, surface pressure, ground temperature, ground wetness and cloud fraction
Numerical techniques	Horizontal spectral differencing, second-order finite difference in the vertical, and central time differencing with Robert semi- implicit corrections
Integration domain	Global, surface to 1 mb
Horizontal resolution:	T159 (~0.75 degree on the Gaussian grid)
Vertical levels:	24 sigma levels with approximately 6 sigma levels below 850 mb, depending on terrain elevation
Forecast time	144 h from the 00Z and 12Z ops run
Initial fields	Machenhauer initialization of increments from the +/- 3 hour cut-off Optimum Interpolation Analysis
First-guess fields	Previous NOGAPS 6-h or 12-h forecast
Orography	Spectrally truncated and Lanczos filtered heights from the U. S. Navy 10 minute field
Horizontal diffusion	Linear, fourth-order LaPlacian for vorticity, divergence and temperature
Moisture physics	Convective precipitation (Emanuel), shallow cumulus mixing (Tiedtke) and large-scale convection
Radiation	Long-wave and short-wave radiation (Harshvardhan) computed every 2 hour
Gravity wave drag	(Palmer, Shutts and Swinbank)
Planetary boundary layer	(Louis)

Table 2: Navy Operational Global Atmospheric Prediction System (NOGAPS) Parameters (After USGODAE web site).

Variables	Conditions
Basic equations	Primitive equations including non-hydrostatic effects
Field formats	Applications grids are latitude- longitude or Cartesian coordinates on horizontal map projection
Variables:	Wind components, potential temperature, mixing ratio, surface pressure, ground temperature, ground wetness, SST
Numerical techniques	Arakawa C-grid, vertically and horizontally staggered with split explicit time integration
Integration domain	Regional, surface to sigma (30) = 31500 m (approx. 10 mb)
Horizontal resolution:	User specified, most often 81 x 27 x 9 km, triple nested
Nested grids	Level of nesting is most often 2 or 3
Forecast time	Nominally 48 h
Initial fields	An MVOI maps both real and synthetic observations from NOGAPS on the model grid. In the incremental update cycle, analysis increments to the first-guess are interpolated in the vertical to the model vertical levels, and added to the most recent model forecast
First-guess analysis	As COAMPS runs in a continuous update cycle, the first-guess fields come from the previous COAMPS forecast
Boundary conditions	Davies (1976) or Parkey-Kreitzbery (1976) treatment of NOGAPS forecast fields
Orography	Envelope topography is from the 1 km terrain data base developed from the DMA DTED level 1 data set
Vertical levels	30 vertical levels on sigma z coordinates

Table 3: Coupled Ocean Atmosphere Mesoscale Prediction System (COAMPS) Parameters (After USGODAE web site).

Data Type Code	PROFILE DATA TYPE	Data Type Code	PROFILE DATA TYPE
0	All Data Combined	21	Ship Bucket
1	Expendable BT	22	Ship Hull Sensor
2	NOAA 14 Day MCSST	23	CMAN SST
3	Ship Engine Room Intake	24	NOAA 15 Day MCSST
4	Fixed Buoy	25	NOAA 15 Night MCSST
5	Drifting Buoy	26	NOAA 15 Relaxed Day MCSST
6	NOAA 14 Night MCSST	27	Mechanical BT
7	NOAA 14 Relaxed Day MCSST	28	Hydrocast BT
8	SSM/I F11 Ice	29	SSM/I F15 Ice
9	SSM/I F13 Ice	30	*In Situ* SSH
10	SSM/I F14 Ice	31	SSM/I Ice Shelf
11	ECMWF Climate	32	TESAC Salinity
12	TOPEX Sea Surface Height	33	MODAS Salinity
13	ERS2 Sea Surface Height	34	TRACK OB Temperature
14	GFO Sea Surface Height	35	TRACK OB Salinity
15	MODAS Temperature	36	PALACE Float Temperature
16	NCEP SST Climate	37	PALACE Float Salinity
17	GOES 9 Day SST	38	MODAS Supplemental far-field temperature
18	GOES 9 Night SST	39	MODAS Supplemental far-field Salinity
19	GOES 9 Relaxed Day SST	40	Supplemental SSH Anomaly
20	TESAC Temperature	41	Supplemental Sea ICE SST

Table 4: Listing of ocean profile types found in format conversion file for USGODAE server (After USGODAE web site).

LIST OF REFERENCES

1. Dimitriou, LCDR David. *"USGODAE Website."* http://www.usgodae.fnmoc.navy.mil/.

2. Fleet Numerical Meteorology and Oceanography Center. Version 1.0. *"GODAE Data Server: System Integration Master Plan."* Dimitriou, LCDR David. pp. 1-22. 22 October 1999.

3. Fleet Numerical Meteorology and Oceanography Center. *"USGODAE: The Strategy."* USGODAE Steering Team. pp. 1-13. 7 December 1999.

4. GODAE International Project Office. Report 6. *"Global Ocean Data Assimilation Experiment. Strategic Plan."* International GODAE Steering Team (IGST). pp. 1-26. December 2000.

5. *"GODAE Website."* http://www.bom.gov.au/bmrc/ocean/GODAE/.

6. http://argo.jcommops.org/

7. International CLIVAR Project Office. Report 21. *"On the Design and Implementation of Argo: A Global Array of Profiling Floats."* Argo Science Team (AST). pp. 1-35. 1998.

8. IOC-WMO-UNEP Committee. *"The Global Ocean Data Assimilation Experiment (GODAE) and the Array for Real-Time Geostrophic Oceanography (Argo)."* Paris/Fourth Session of the IOC-WMO-UNEP Committee for the Global Ocean Observing System (GOOS). 23-25 June 1999.

9. *"Report of the Argo Workshop."* http://www.bom.gov.au/bmrc/mrlr/nrs/oopc/godae/2ndIGST/ArgoWS1.html.

10. Roemmich, Dean and Owens, W. Brechner. *"The Argo Project: Global ocean observations for understanding and prediction of climate variability."* Oceanography. Vol. 13. No. 2. pp. 45-50. 2000.

11. Schmitt, Ray *"A program for Global for Global Ocean SAlinity MonitORing (GOSAMOR)."* 1998.

12. Smith, Neville and Lefebvre, Michel. *"The Global Ocean Data Assimilation Experiment."* Biarritz, France/International Symposium. Monitoring the Oceans in the 2000s: An Integrated Approach. 15-17 October 1998.

13. Wilson, Stan. *"Launching the Argo Armada."* Oceanus. Vol. 42. No. 1. pp. 17-19. 2000.

14. Woods Hole Oceanographic Institution. *"Observing the Ocean...in Real Time. Argo: A Global Array of Profiling Floats. To Understand and Forecast Climate."* Gwynne, Peter. pp. 1-11. June 1999.

INITIAL DISTRIBUTION LIST

1. Defense Technical Information Center 2
   8725 John J. Kingman Road, Suite 0944
   Ft. Belvoir, VA 22060-6218

2. Dudley Knox Library 2
   Naval Postgraduate School
   411 Dyer Road
   Monterey, CA 93943-5101

3. Professor Mary Batteen 5
   Oceanography Department
   Naval Postgraduate School
   1 University Way
   Monterey, CA 93940

4. LCDR David Dimitriou 2
   Fleet Numerical Meteorology and Oceanography Center
   7 Grace Hopper Avenue, Stop 1
   Monterey, CA 93943

5. Professor Roland W. Garwood 1
   Oceanography Department
   Naval Postgraduate School
   1 University Way
   Monterey, CA 93940

6. LT Timothy A. Anderson 3
   11307 Sahler St.
   Omaha, NE 68164